Beneath the Surface:
Sulfide Mining and Human Health

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Beneath the Surface: Sulfide Mining and Human Health

Objectives:

- Describe potential public health impacts associated with sulfide mining, including environmental exposures and related health considerations
- Identify the role of family physicians in recognizing, addressing, and communicating health concerns related to sulfide mining in their communities

American Medical Association (AMA) Code of Medical Ethics

Although physicians' primary ethical obligation is to individual patients, they also have a responsibility to protect and promote public health.

AMA Code of Medical Ethics, Chapter 8, available at https://code-medical-ethics.ama-assn.org/chapters/physicians-health-community, accessed 9/20/23.

Mining for metals

- Currently, nearly all metals originate in the ground
- Require extraction by process of metallic mining
- Desired metal is found within an ore body
- Typically, massive amounts of waste rock are generated
- Often, further purification processes are needed (e.g. smelting)
- Target metal is a very small amount of the total ore body (often <1%)

Quick Primer on 4 Primary Methods of Mining

- Surface mining
  - Open pit
  - Strip
  - Mountaintop removal
- Underground mining
  - Tunnels
  - Shafts
  - Deep in earth
- Placer mining
  - Water often used to separate materials
  - Loose deposits (e.g. riverbeds)
- In-situ mining (solution mining)
  - Solution injected to dissolve
  - Materials in original location

Open pit vs Underground Mining Methods, Explained Simply
0:57 length

Iron mine, Sulfide mine
Examples shown are both surface mines

Iron ore (taconite) mining

Photo courtesy of http://rvingbeachbums.blogspot.com/2014/11/iron-ore-mines-of-hibbing-mn.html, accessed on March 7th, 2017

Sulfide (copper-nickel) mining

Photo courtesy of https://toursofutah.com/kennecott-utah-bingham-canyon-copper-mine-tour/, accessed March 7th, 2017

Iron Ore and Sulfide Ore General Characteristics

Iron ore (taconite) mining

- Rock containing iron-bearing minerals (includes iron oxides and iron carbonate) has less sulfur
- General reaction with air/water = rust
- Mining rock & waste less likely to produce acid (although still may increase mercury contamination of fish)

Sulfide ore (copper-nickel) mining

- Ore body contains sulfide minerals
- Reaction with air/water = H^+, SO_4^{2-} (sulfate), H_2SO_4 (sulfuric acid)
- General reaction with air/water can produce acid, sulfate
- Potential for release of heavy metals in ore

Poveromo JJ. Iron ores. In: Wakelin DH, Fruehan RJ, eds. The Making, Shaping and Treating of Steel. 11th ed. Pittsburgh, PA: The AISE Steel Foundation; 1999:547-642.

Sulfide Mining

Desired metals in a mining operation, such as copper, nickel, palladium group metals, can be bound to sulfur in rock. Because of this sulfur bond, they are described as *sulfide minerals*. There are many chemical compounds within this category.

Mining these *sulfide minerals* is referred to as sulfide mining.

Millions of tons of rock are excavated to obtain a fractional amount of the desired product.

Jacobs JA, Lehr JH, Testa SM.
Acid Mine Drainage, Rock Drainage and Acid Sulfate Soils: Causes, Assessment, Prediction, Prevention and Remediation. Hoboken, NJ: John Wiley & Sons; 2014.

Examples of Cu, Ni minerals

Copper:

Chalcopyrite $CuFeS_2$

Chalcocite Cu_2S

Nickel:

Pentlandite $(Fe,Ni)_9S_8$

Pyrrhotite $(Fe,Ni)_{1-x}S_x$

Identify Major Toxins Associated with Sulfide Minerals

Ore that contains the commercially desired metals often contains other metals like mercury, lead and arsenic, similarly bound to sulfur. Examples include:

- Arsenic (arsenopyrite or $FeAsS$)
- Cadmium sulfide (CdS)
- Copper (chalcopyrite or $CuFeS_2$)
- Lead (galena or PbS)
- Manganese sulfide (MnS)
- Mercury (cinnabar or HgS)
- Zinc (sphalerite or $[(ZnFe)S]$)

Jacobs JA, Lehr JH, Testa SM.
Acid mine drainage, rock drainage,
and acid sulfate soils: causes, assessment, prediction,
prevention, and remediation.
Hoboken, NJ: John Wiley & Sons; 2014.

Identify major toxins associated with sulfide mining

World Health Organization's Chemicals of Major Public Health Concern:

- **Air pollution***
- **Arsenic***
- **Asbestos***
- Benzene
- **Cadmium***
- Dioxin & Dioxin-like substances
- Inadequate or excess Fluoride
- **Lead***
- **Mercury***
- Highly hazardous pesticides

World Health Organization. Preventing disease through healthy environments: Action is needed on chemicals of major public health concern. Geneva: World Health Organization; 2010. Available at: www. who.int/ipcs/features/10chemicals_en.pdf?ua=1.

Sulfide mining health considerations: Air Pollution

- Airborne particulates including fugitive dust, silica dust
- Additional air pollution (directly from mining activity as well indirect impacts from electrical power generated using fossil fuel sources)
- Inhaled, small particles lead to oxidative stress and inflammation

Image of truck with fugitive dust accessed from https://www.thermofisher.com/blog/mining/is-your-fugitive-dust-control-plan-effective-enough/ on March 7th, 2017.

- HEALTH EFFECTS are numerous:
  - Increased risk cardiovascular event
  - Long term increased risk of hardening of arteries
  - Increased risk of blood clots
  - Increased tendency toward metabolic imbalances
  - Emerging evidence if increased dementia risk

Sulfide mining health considerations: Asbestos & Elongate Mineral Fibers (EMF)

- ✓ Mineral fibers released as rock is blasted, mined, crushed, dumped, etc.
- ✓ Asbestos and asbestiform fibers
- ✓ HEALTH EFFECTS of asbestos include lung disease and mesothelioma
- ✓ HEALTH EFFECTS OF EMFs are being studied, complex

Sulfide mining health considerations: Heavy metals

Arsenic (As) Cardiovascular, skin, carcinogen; route of exposure often drinking water

Lead (Pb) Nervous system, blood, cardiovascular, kidneys, probable carcinogen; route of exposure can be paint, soil, H_20

Mercury (Hg) Nervous system, kidney, possible carcinogen; route of exposure can be air & food

Cadmium (Cd) Respiratory, kidney, carcinogen (lung); exposure route can be occupational, food, smoking

Nickel (Ni) Respiratory, skin (allergy), carcinogenic soluble Ni compounds, possibly carcinogenic metallic Ni (lung); often occupational exposure

Manganese (Mn) Neurotoxic (Parkinson-like symptoms), cardiotoxicity, hepatotoxicity, cognitive impairment, increased infant mortality; drinking water limits

Sulfide mining health considerations: Unanticipated disruptions & failures

- Unanticipated interruption of water treatment
- Extreme weather event that overwhelms operation
- Catastrophic event such as tailing dam breach
- Contamination and destruction of food sources, livelihoods
- Human loss of life

Photo above:
Dam breach at Mount Polley Mine in British Columbia, Canada, August 4, 2014. Image taken by NASA's Operational Land Imager on Landsat8 satellite.Available courtesy of NASA Earth Observatory At http://earthobservatory.nasa.gov/IOTD/view.php?id=84202&src=ve.

Concerns about proposed mining operations in MN:

No liners to contain and collect toxic seepage.

No effluent limits on wastewater plant for mercury, sulfate, toxic metals.

Tailings Design:
Upstream dam most likely to collapse & contaminate downstream waters.

Catastrophic Tailings Pond & Dam Failures
- Mount Polley (2014), Canada
- Samarco (2015), Brazil, 19 killed/missing
- Brumadinho (2019), 300 lives lost

Photo by Romerito Pontes from São Carlos licensed under the Creative Commons Attribution 2.0 Generic license.

An aerial view of the Mount Polley mine tailings pond shows the area where the earthen wall gave way.
Photo credit: https://www.cbc.ca/news/canada/british-columbia/mount-polley-mine-ex-engineers-warned-tailings-pond-getting-large-1.2732314

What entity oversees mine safety?

Mine Safety and Health Administration (MSHA)

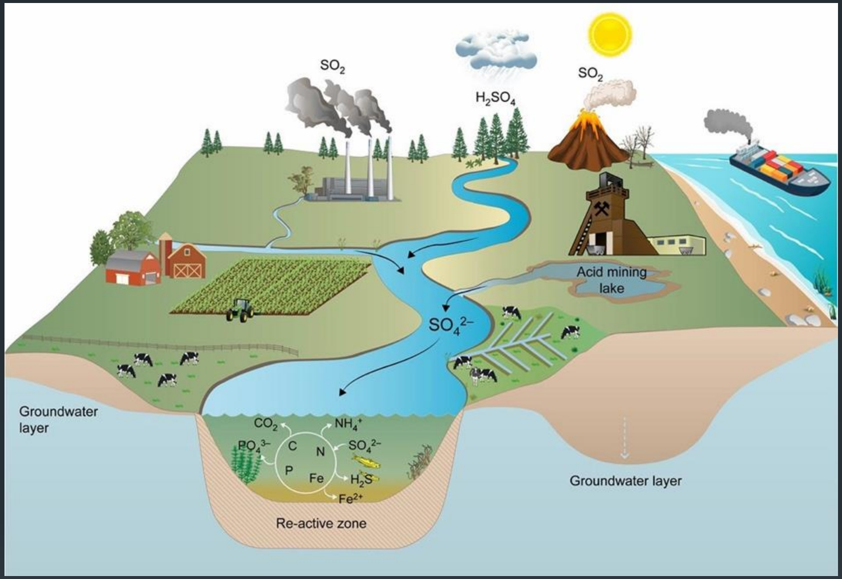
MSHA is required to inspect each underground mine four times a year and each surface mine twice a year for health and safety compliance. Certain mines with high levels of explosive or toxic gasses are inspected more often.*

According to a recent U.S. Department of Labor Office of Inspector General Audit, MSHA did not complete an estimated **1,589** mandatory mine inspections during Fiscal Year 2018 - Fiscal Year 2021, although it reported a nearly 100 percent completion rate.**

- * According to the Mine Safety and Health Administration's website on Mine Inspections, accessed 2026, available at https://www.msha.gov/compliance-and-enforcement/mine-inspections.
- ** MSHA Did Not Complete Or Accurately Report Mandatory Inspections, U.S. Department of Labor, Office of Inspector General, Office of Audit, REPORT NUMBER: 19-24-001-06-001, October 17. 2023. Available at https://www.oig.dol.gov/public/reports/oa/2024/19-24-001-06-001.pdf.

Sulfide mining health considerations: Sulfate release

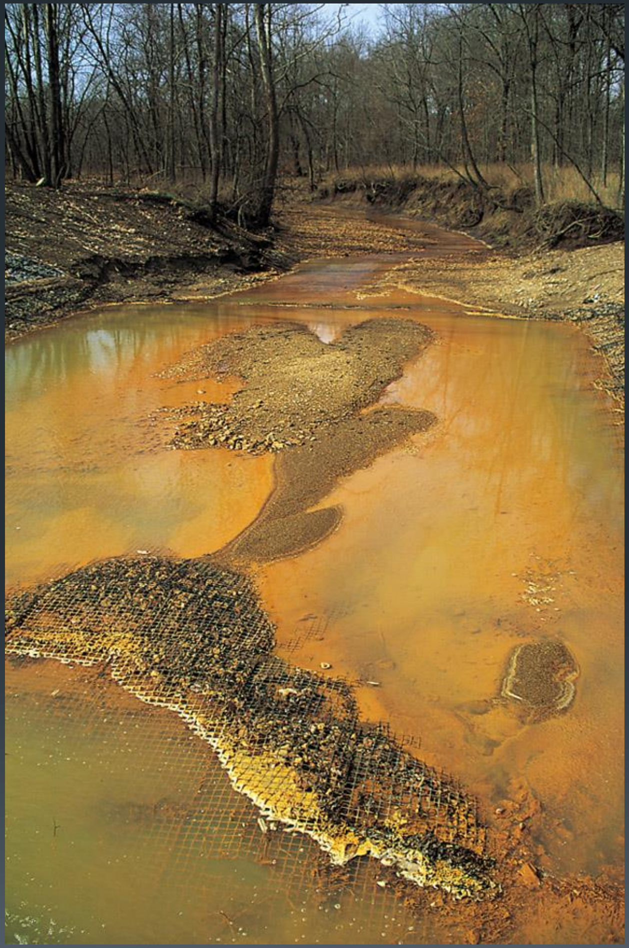
- Anthropogenic pollution of freshwater systems is an ongoing global issue
- Aquatic flora and fauna can be severely impaired by sulfate pollution
- Minnesota's native wild rice stands are negatively impacted by sulfate and sulfide exposures



Sulfate in Freshwater Ecosystems

Dominik Zak, Michael Hupfer, Alvaro Cabezas, Gerald Jurasinski, Joachim Audet, Andreas Kleeberg, Robert McInnes, Søren Munch Kristiansen, Rasmus Jes Petersen, Haojie Liu, Tobias Goldhammer. **Sulphate in freshwater ecosystems: A review of sources, biogeochemical cycles, ecotoxicological effects and bioremediation,** Earth-Science Reviews, Volume 212, 2021,103446, ISSN 0012-8252, https://doi.org/10.1016/j.earscirev.2020.103446

ACID MINE DRAINAGE



As rock is blasted and pulverized to release ore, it is exposed to air and water, forming sulfuric acid. Results in acid mine drainage and leaches toxic metals.

Iron hydroxide precipitating in a stream can be seen as the yellow-brownish discoloration, sometimes referred to as ‘ochre’ or ‘yellowboy’.

Photo courtesy of the U.S. Geological Survey. 1998. Status and trends of the nation’s biological resources. Vol. 1. Reston, VA: U.S. Department of the Interior. Available at: http://www.nwrc.usgs.gov/sandt/.

Pyrite Oxidation Sequence: Stoichiometry of how sulfide-bearing rock reacts with oxygen and water to create sulfuric acid

(1) $2\,FeS_{2\,(solid)}$ (pyrite) $+ 7\,O_2 + 2\,H_2O \rightarrow 2\,Fe^{2+} + 4\,SO_4{}^{2-}{}_{(aq)}$(sulfate) $+ 4\,H^+{}_{(aq)}$

(2) $4\,Fe^{2+}{}_{(aq)} + O_2 + 4\,H^+{}_{(aq)} \rightarrow 4\,Fe^{3+}{}_{(aq)} + 2\,H_2O$

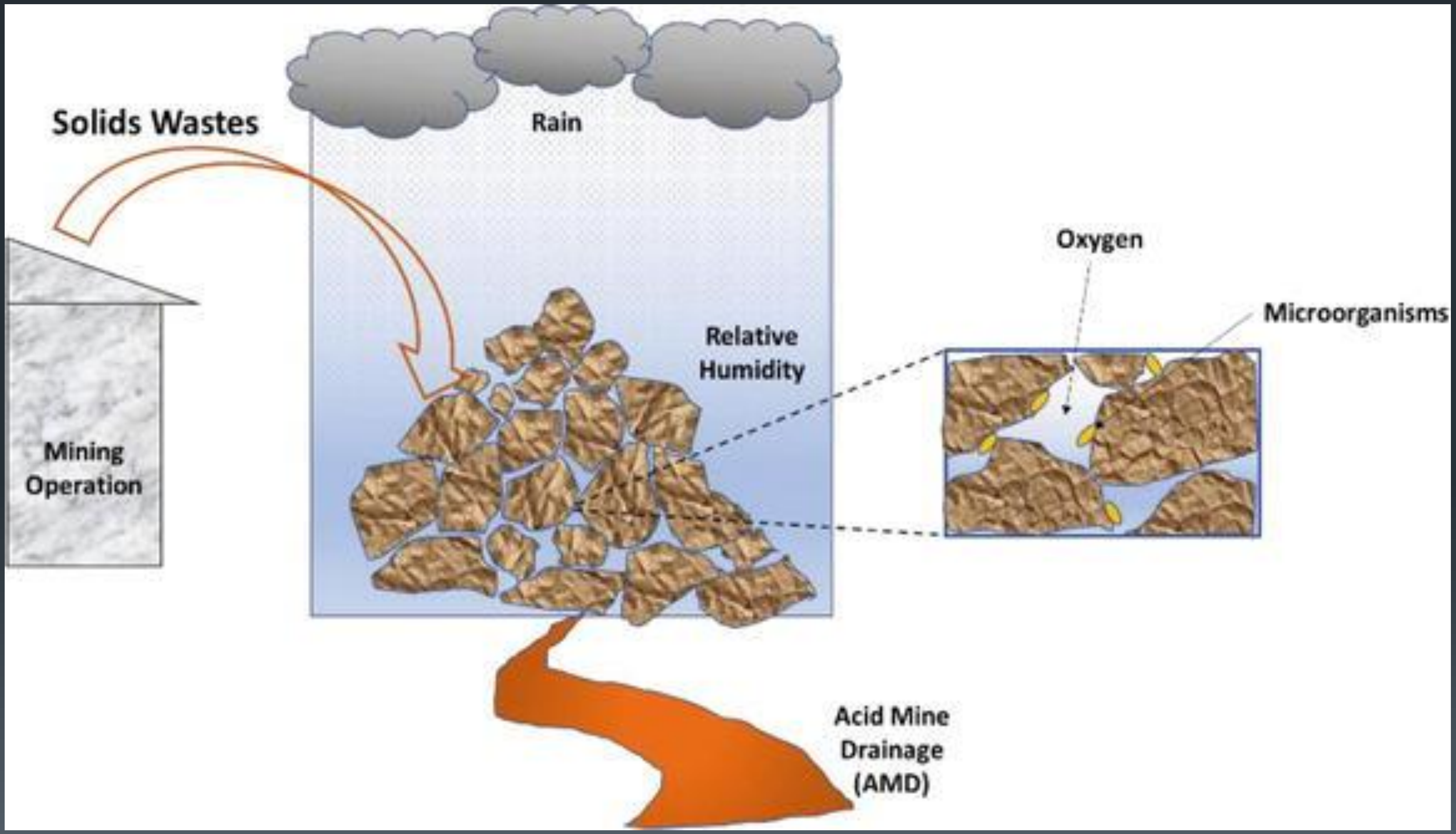
(3) $2\,Fe^{3+} + 6\,H_2O \leftrightarrow 2\,Fe(OH)_{3(solid)}$ (ferric hydroxide) $+ 6\,H^+{}_{(aq)}$

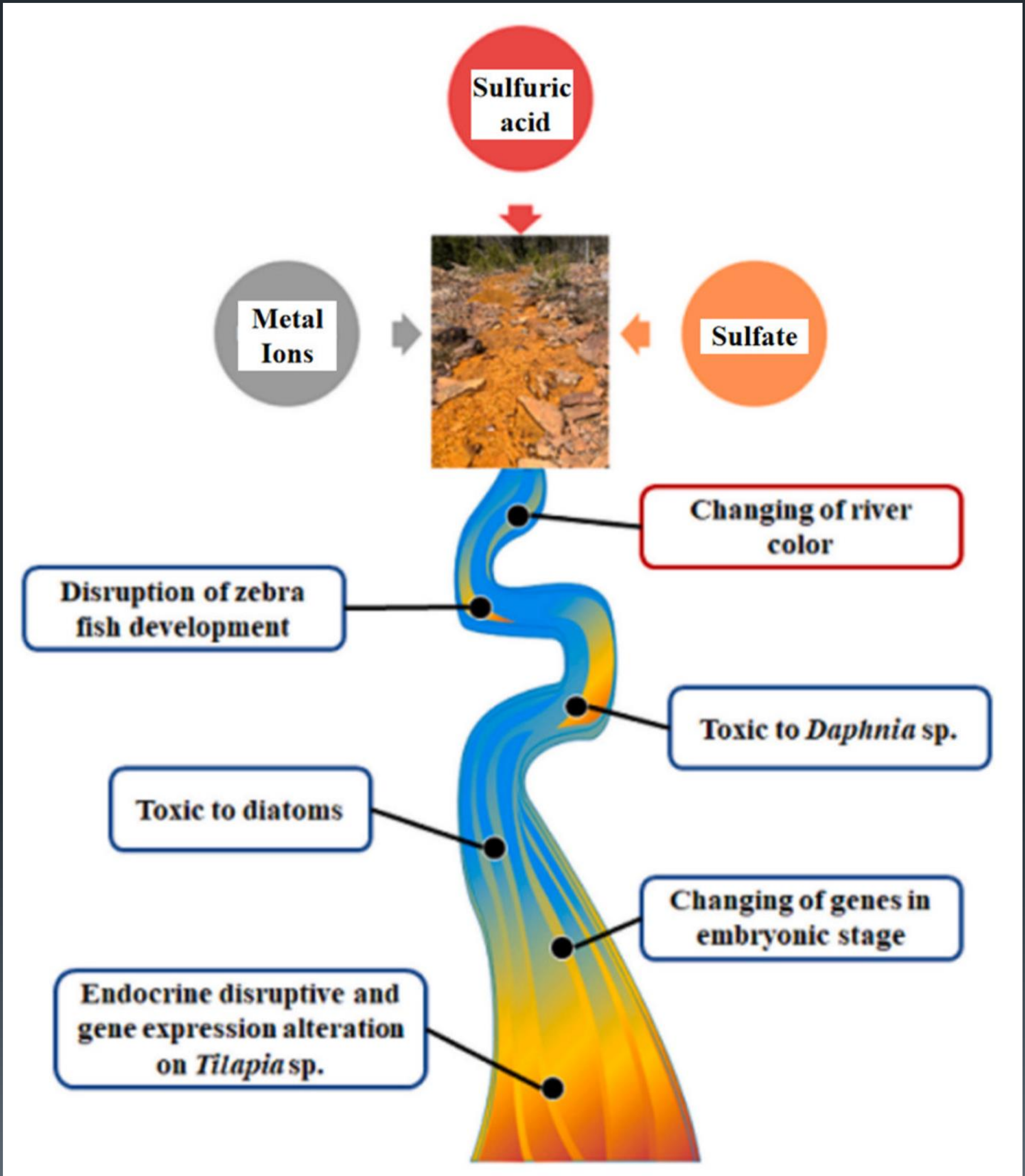
(4) $14\,Fe^{3+} + FeS_{2(solid)} + 8\,H_2O \rightarrow 15\,Fe^{2+}{}_{(aq)} + 2\,SO_4{}^{2-} + 16\,H^+{}_{(aq)}$

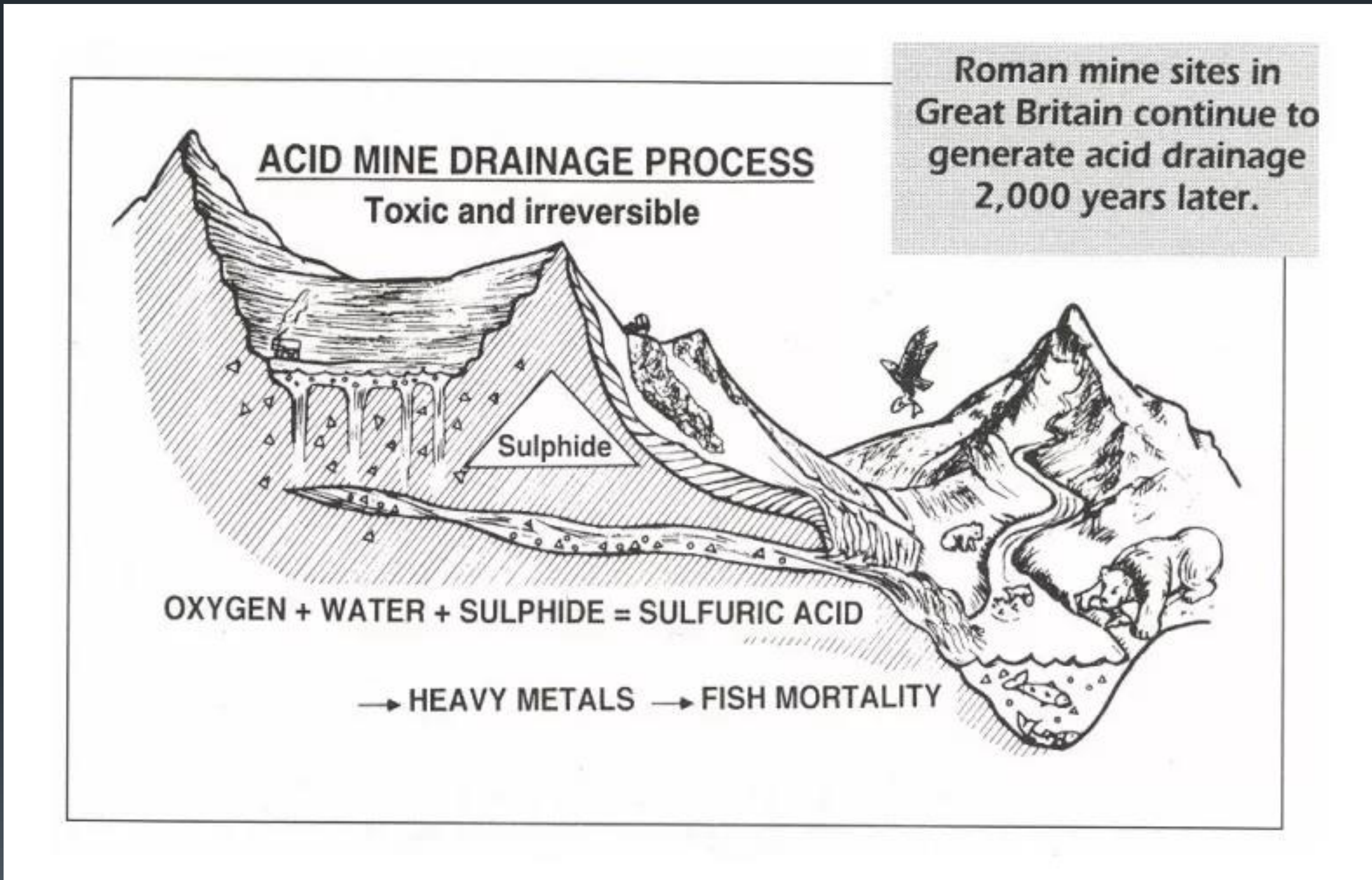
(5) $FeS_{2(solid)} + 7\,Fe_2(SO_4)_{3(aq)} + 8H_2O \rightarrow 15\,FeSO_{4(aq)} + 8\,H_2SO_4$ (sulfuric acid)

Jacobs JA, Lehr JH, Testa SM. Acid mine drainage, rock drainage, and acid sulfate soils: causes, assessment, prediction, prevention, and remediation. Hoboken, NJ: John Wiley & Sons; 2014, p. 24.

Scheme of acid mine drainage (AMD) production

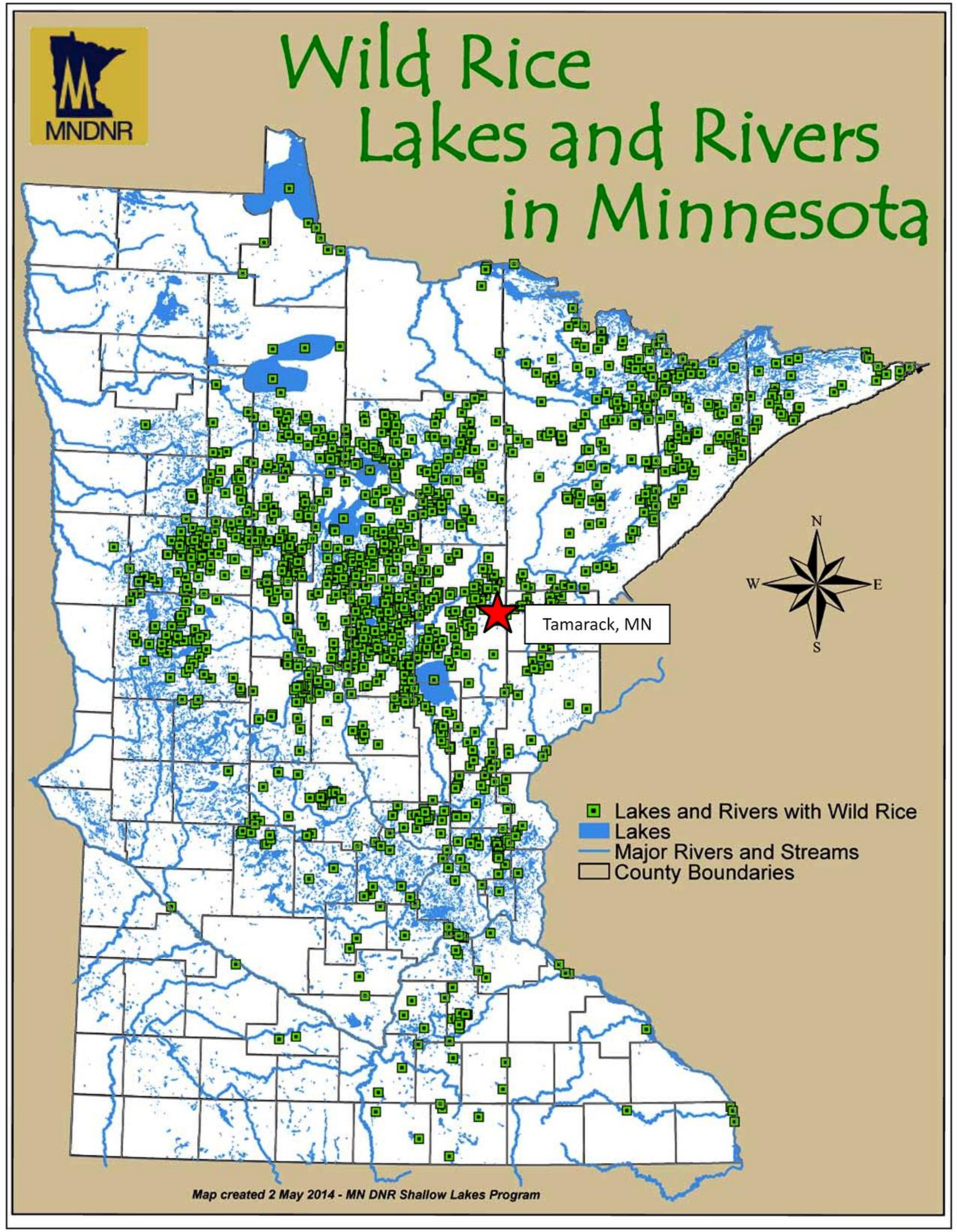



Sulfuric acid
Metal Ions
Sulfate
Changing of river color
Disruption of zebra fish development
Toxic to *Daphnia* sp.
Toxic to diatoms
Changing of genes in embryonic stage
Endocrine disruptive and gene expression alteration on *Tilapia* sp.


Roman mine sites in Great Britain continue to generate acid drainage 2,000 years later.
ACID MINE DRAINAGE PROCESS
Toxic and irreversible
Sulphide
OXYGEN + WATER + SULPHIDE = SULFURIC ACID
→ HEAVY METALS → FISH MORTALITY

Manoomin, Psíŋ

- Seed of an aquatic grass
- Indigenous peoples have harvested for millennia
- Culturally very important
- Shelf stable, gluten free, offers food security
- Very favorable nutritional profile


Wild Rice
Lakes and Rivers
in Minnesota
MNDNR
Tamarack, MN
N
W
E
S
Lakes and Rivers with Wild Rice
Lakes
Major Rivers and Streams
County Boundaries
Map created 2 May 2014 - MN DNR Shallow Lakes Program

Significant cultural considerations of wild rice:

- Data support the connection between participation in traditional practices and improved health (Sasakamoose et al 2017)
- In addition to manoomin's cultural and spiritual importance, it is a nutritionally advantageous grain, with a favorable cardioprotective profile offering omega-3 fats, B vitamins, and desirable levels of protein, fiber, carbohydrate, and total fat (Tim and Slavin 2014)
- Aqueous sulfates released into the ecosystem from anthropogenic sources like SOCN mining are converted to sulfides which are toxic to wild rice growth. Wild rice does not grow in waters with high levels of sulfate (Myrbo et al. 2017).
- Fond du Lac Band of Lake Superior Chippewa: Health Impact Assessment concluded that the persistent health disparities for tribal communities in Minnesota are directly related to the involuntary loss of traditional lands, subsequent disruption of traditional lifeways and the loss of traditional, health-sustaining foods such as manoomin.

Microorganisms <u>can speed </u>up the oxidation reactions significantly

Acidithiobacillus ferrooxidans magnification 30,000 times.

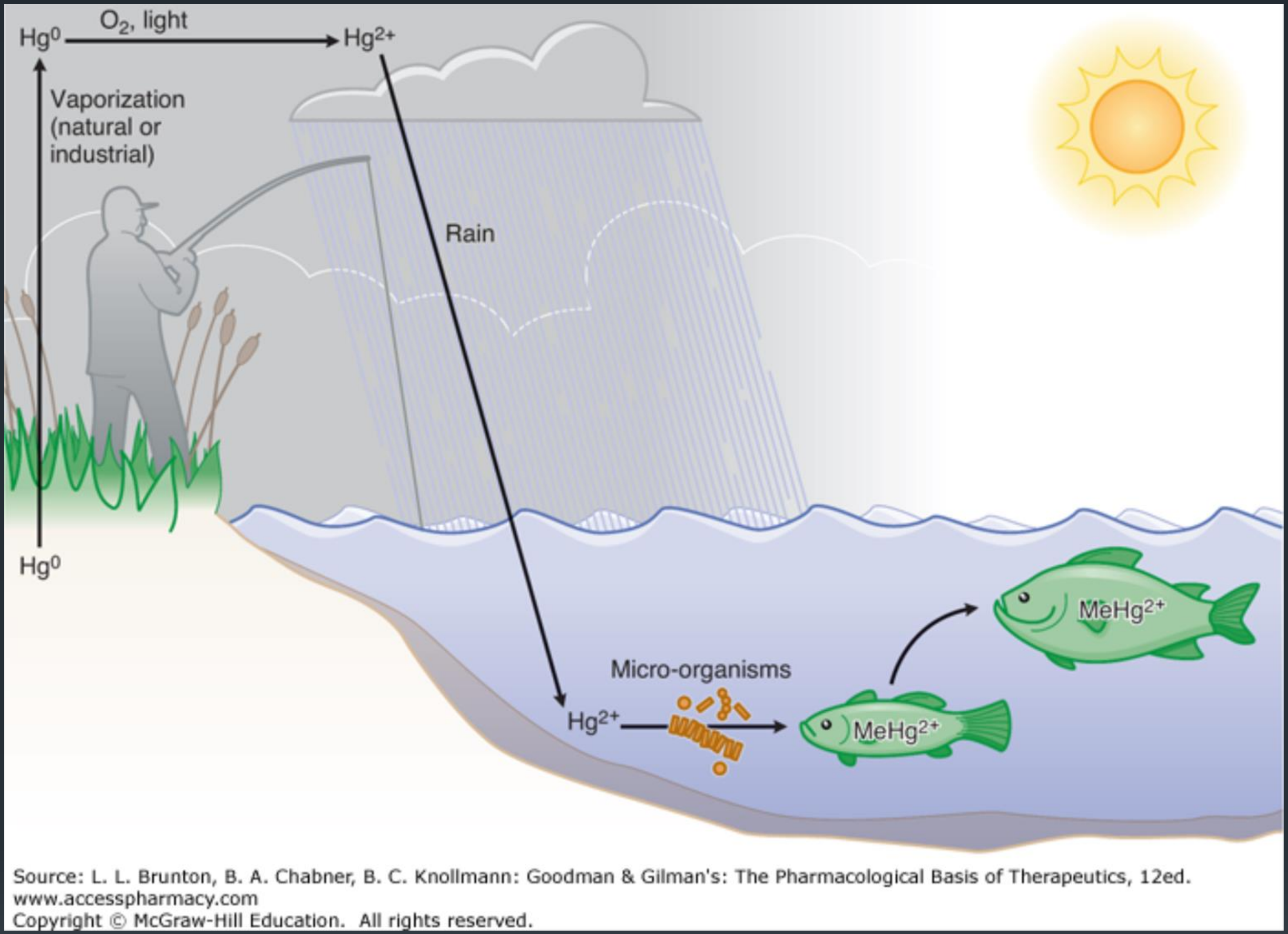
Photo courtesy of Henry Lutz Ehrlich, Geomicrobiology, 2nd edition, (New York: Marcel Dekker, 1990)

Microorganisms significantly speed up mercury methylation

Mercury methylation by microorganisms occurs in sediments, wetlands, ombrotrophic (“cloud fed”) bogs and peat lands that are found in Minnesota’s water rich environment.

Jeremiason JD, Engstrom DR, Swain EB, et al. Sulfate addition increases methylmercury production in an experimental wetland. Environ Sci Technol. 2006;40(12):3800-6.

Branfireun BA. Of the NorthMet mining project and land exchange: Final environmental impact statement 2015. Expert Report. Available at: http://waterlegacy.org/sites/default/files/u42412/Branfireun_Expert_Opinion_PolyMet_FEIS_(FinalDraftDec.2,2015)(1).pdf. Accessed August 14, 2016.

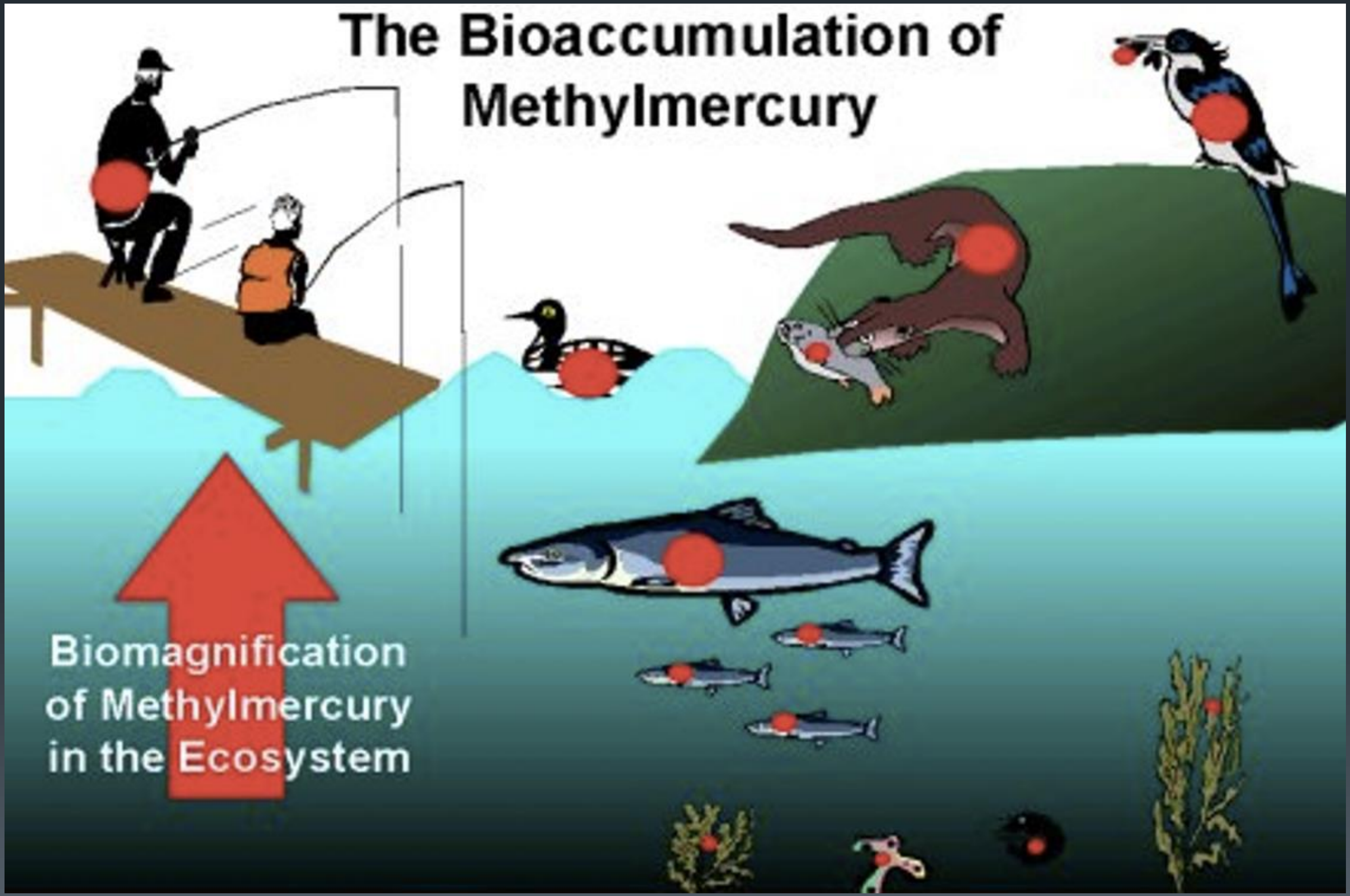


Mobilization of mercury in the environment. Metallic mercury (Hg^0) is vaporized from the Earth's surface both naturally and through human activities such as burning coal. In the atmosphere, Hg^0 is oxidized to form divalent inorganic mercury (Hg^{2+}). Hg^{2+} then falls to the surface in rain. Aquatic bacteria can methylate Hg^{2+} to form methyl mercury ($MeHg^+$). $MeHg^+$ in plankton is consumed by fish. Because of its lipophilicity, $MeHg^+$ bioaccumulates up the food chain.

Source: Environmental Toxicology: Carcinogens and Heavy Metals, *Goodman & Gilman's: The Pharmacological Basis of Therapeutics, 12e*

Citation: Brunton LL, Chabner BA, Knollmann BC. *Goodman & Gilman's: The Pharmacological Basis of Therapeutics, 12e*; 2011 Available at: http://accessmedicine.mhmedical.com/content.aspx?sectionid=102164854&bookid=1613&Resultclick=2 Accessed: March 04, 2017

Methylmercury Bioaccumulation and Biomagnification:



Sequence of events by which release of anthropogenic sulfate can result in increased mercury levels in fish, and ultimately humans.

- Release of sulfate into the environment from anthropogenic source (example: acid mine drainage)
- Sulfate reaches wetlands where it can stimulate certain "sulfate-breathing" microorganisms that are capable of converting inorganic mercury to methyl mercury
- Enhanced rates of mercury methylation can occur
- Methylmercury bioaccumulates in aquatic ecosystems, including fish species
- Humans consume mercury-contaminated fish

1. Jeremiason JD, Engstrom DR, Swain EB, et al. Sulfate addition increases methylmercury production in an experimental wetland. Environ Sci Technol. 2006;40(12):3800-6.
2. Branfireun BA. Of the NorthMet mining project and land exchange: Final environmental impact statement 2015. Expert Report. Available at: http://waterlegacy.org/sites/default/files/u42412/Branfireun_Expert_Opinion_PolyMet_FEIS_(FinalDraftDec.2,2015)(1).pdf. Accessed August 14, 2016.

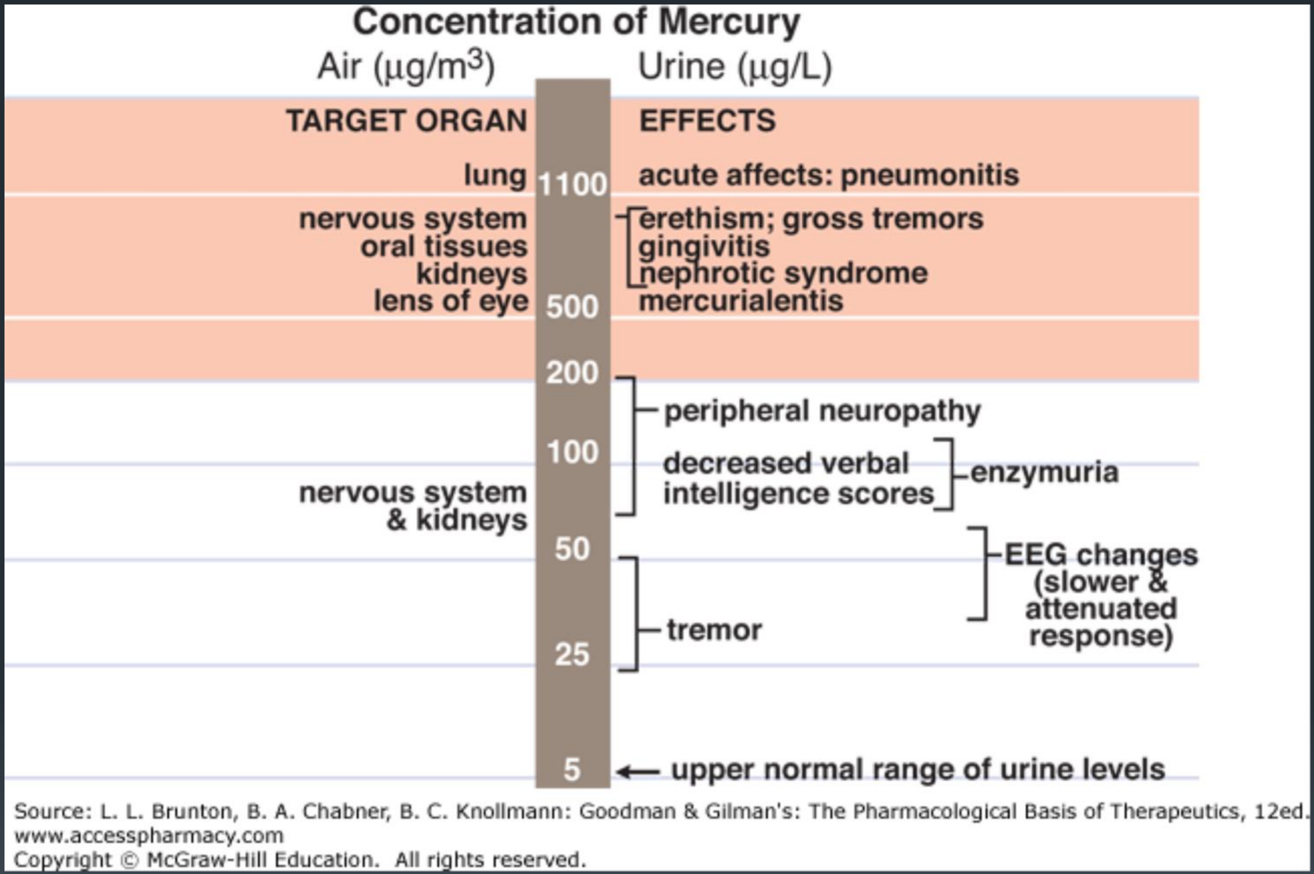
Mercury’s toxic impact on human health

The causes of neurodevelopmental disorders, including ADD, learning disorders, autism spectrum disorder, language disorders and intellectual disabilities are complex and multifactorial, but the connection to exposures to heavy metals, particularly methyl mercury, is known.

Bennett D, Bellinger DC, Birnbaum LS, et al. Project TENDR: Targeting environmental neurodevelopmental risks the TENDR consensus statement. Environ Health Perspect. 2016;124(7):A118-22.

Photo by Scott Housely, 2015 courtesy of the Center for Disease Control, content provided byJulia Whitney, Stephen Griffin

Review how these toxins can impact human health



The concentration of mercury vapor in the air and related concentrations of mercury in urine are associated with a variety of toxic effects.

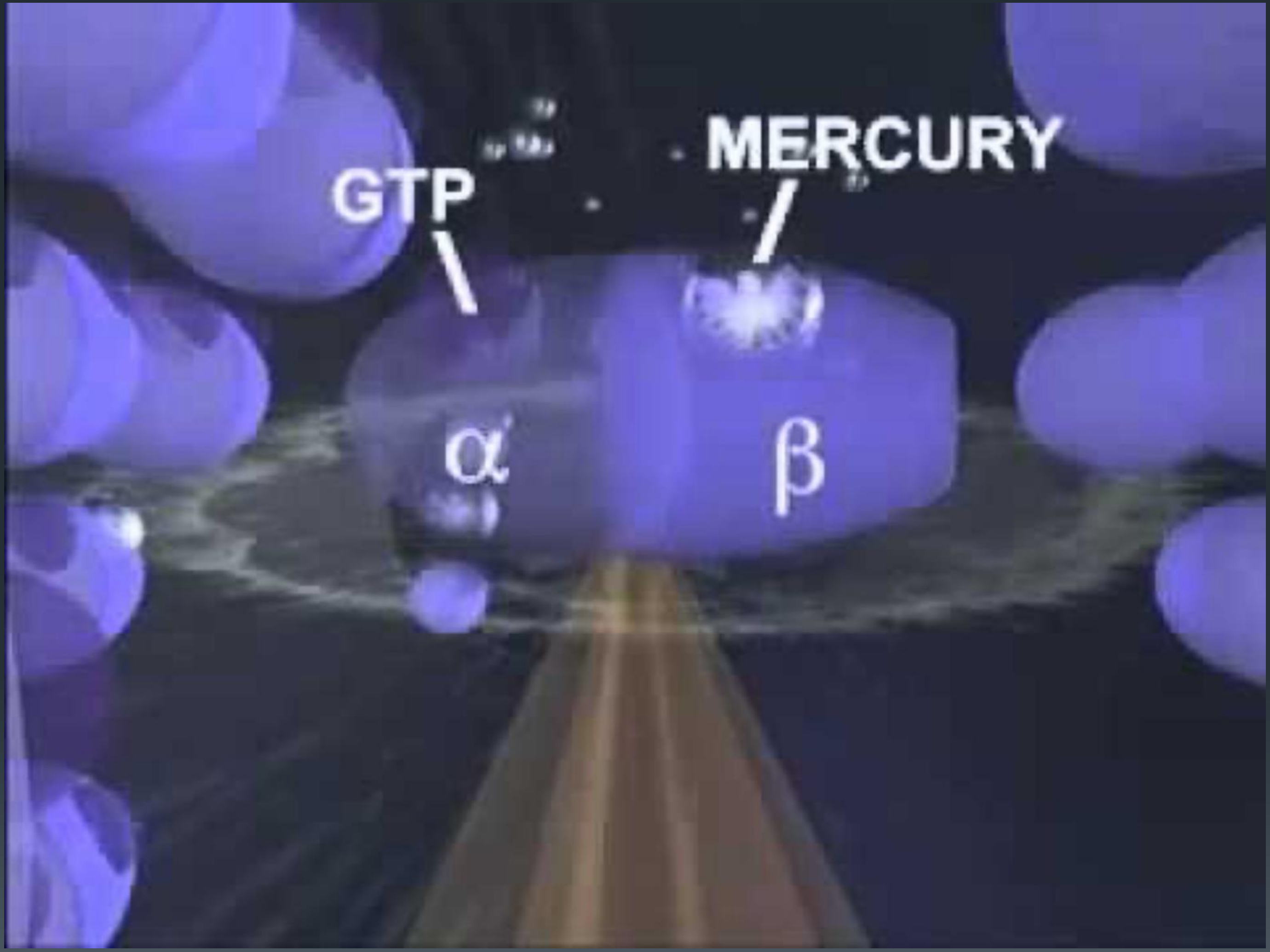
Source: Environmental Toxicology: Carcinogens and Heavy Metals, *Goodman & Gilman's: The Pharmacological Basis of Therapeutics, 12e*

Citation: Brunton LL, Chabner BA, Knollmann BC. *Goodman & Gilman's: The Pharmacological Basis of Therapeutics, 12e*; 2011 Available at: http://accessmedicine.mhmedical.com/content.aspx?sectionid=102164854&bookid=1613&Resultclick=2 Accessed: March 04, 2017

Key mechanisms of neurotoxicity of Hg

- **Oxidative Stress & Mitochondrial Dysfunction:** Mercury induces the production of Reactive Oxygen Species (ROS) such as superoxide and hydrogen peroxide. It inhibits antioxidant enzymes like glutathione peroxidase, leading to the depletion of glutathione (GSH). This triggers severe mitochondrial dysfunction, disrupting the cell's energy supply and leading to apoptosis.
- **Binding to Sulfhydryl/Selenol Groups:** Mercury, especially methylmercury, has an extremely high affinity for sulfhydryl (-SH) and selenol (-SeH) groups found in enzymes and structural proteins. This binding directly inhibits protein function.
- **Disruption of Calcium Homeostasis:** Mercury exposure increases intracellular calcium (Ca^{2+}) levels. This accumulation of Ca^{2+} triggers uncontrolled activation of enzymes, causing mitochondrial damage and altering neurotransmitter release.
- **Excitotoxicity & Neurotransmitter Disruption:** Mercury interferes with the transport of glutamate—the brain's main excitatory neurotransmitter—resulting in its accumulation in the synaptic cleft, which causes excitotoxicity and kills neurons. It also inhibits inhibitory GABA signaling, leading to imbalances in the central nervous system.
- **Blood-Brain Barrier (BBB) Dysfunction:** Mercury readily crosses the blood-brain barrier. Methymercury uses the L-type amino acid transporter to enter the brain, where it can later be converted into inorganic mercury and become trapped, causing chronic damage.
- **Neuroinflammation:** Non-cytotoxic levels of methylmercury can activate microglia and astrocytes, leading to an inflammatory response within the central nervous system, particularly during neurodevelopment.
- **Microtubule Destruction & Cytoskeleton Collapse:** Mercury breaks down microtubules—essential structural components of nerve fibers—by binding to tubulin. This causes neurite retraction, growth cone collapse, and inhibits cell migration, which is especially critical for developing brain tissues.

How mercury causes brain neuron degeneration



Available on Youtube at https://www.youtube.com/watch?v=xf6uCw2ztxw.
F.L. Lorsheider, C.C-W. Leong, N.I. Syed, Department of Physiology and Biophysics, Faculty of Medicine, University of Calgary, Canada, 2001. Duration: 4:59

Those most vulnerable:

- Developing fetus (pregnant women)
- Infants and children (lactating mothers)
- People dependent on local fish as quality protein source
- People for whom ingestion of freshwater fish is important cultural and dietary practice

Why is mercury so toxic for the developing nervous system?

- Placenta is unable to filter out heavy metals
- Once heavy metals reach nerve or brain tissue the amount of damage is proportional to the rate of growth and cell division of the tissues *(brain size doubles in the first year of life and by age 3 is approx. 80% adult volume)*
- Lasting negative effects when fetuses are exposed to concentrations at levels that are only 10%-20% of toxic levels for adults

Minnesota Department of Health study

- Published 2011
- Heel cord blood from newborn babies in Western Lake Superior Basin (MN, WI, and MI)
- Significant elevations in mercury found in 10% of newborns
- Methylmercury exposure is already a public health issue in northeastern Minnesota

Mercury Levels in Blood from Newborns in the Lake Superior Basin
GLNPO ID 2007-942
Final Report
November 30, 2011
Submitted by: Patricia McCann
Minnesota Department of Health Division of Environmental Health

Newborn blood and Hg study

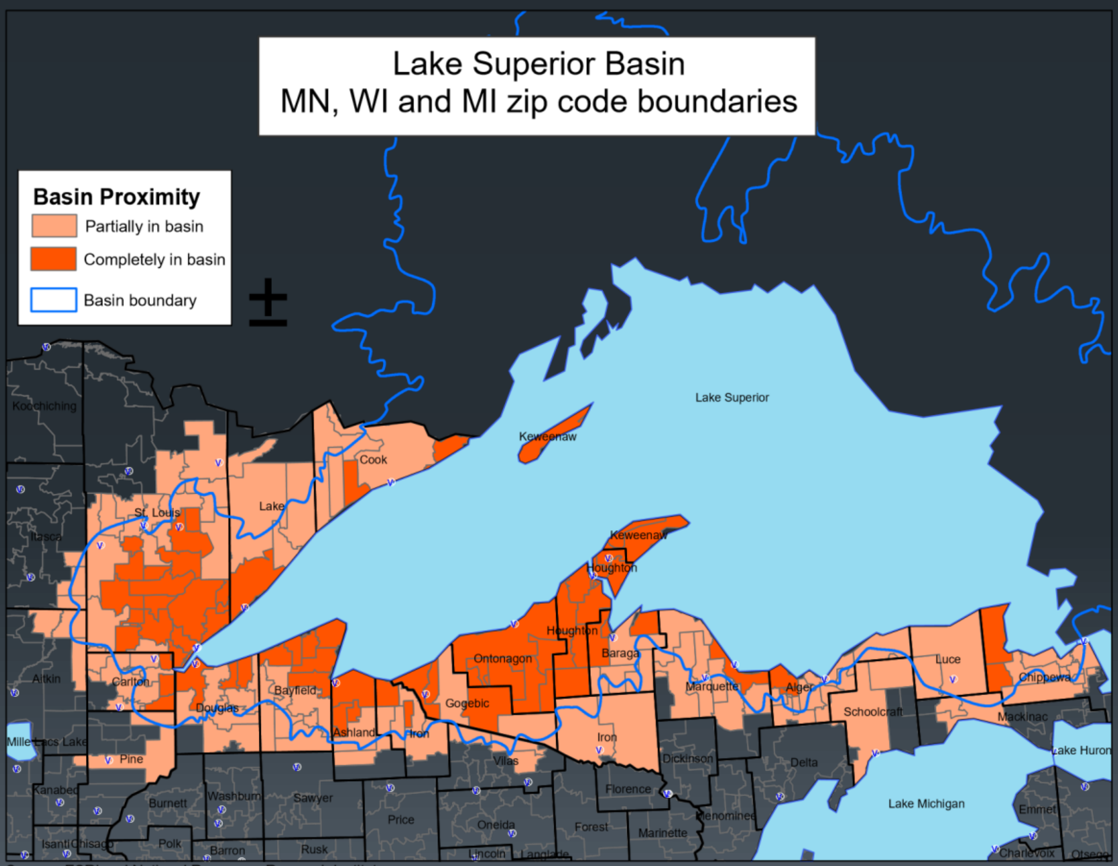
- Minnesota Department of Health led the investigation
- Residual dried blood spots collected from newborn screening
- Notable exclusion criteria (e.g., sick baby, abnormal NBS)
- Punched out discs from dried blood spots on filter paper were analyzed for total mercury
- Analysis performed at MN Dept of Health's Public Health Laboratory
- Lake Superior basin region (MN, WI, MI)

NBS = Newborn Screen

McCann P. Mercury levels in blood from newborns in the Lake Superior Basin (GLNPO ID 2007-942). Final Report. November 30, 2011. Available at: www.health.state.mn.us/divs/eh/hazardous/topics/studies/glnpo.pdf.

Geographic region of Newborn blood and Hg study

Figure 2. Lake Superior Basin



Source: ESRI and National Resources Research Institute

McCann P. Mercury levels in blood from newborns in the Lake Superior Basin (GLNPO ID 2007-942). Final Report. November 30, 2011. Available at: www.health.state.mn.us/divs/eh/hazardous/topics/studies/glnpo.pdf.

Participant characteristics

Total n = 1,465

- Minnesota = 1,126 (77%)
- Wisconsin = 139 (9%)
- Michigan = 200 (14%)

Gender

- Male = 730 (50%)
- Female = 733 (50%)
- Unknown = 2 (0%)

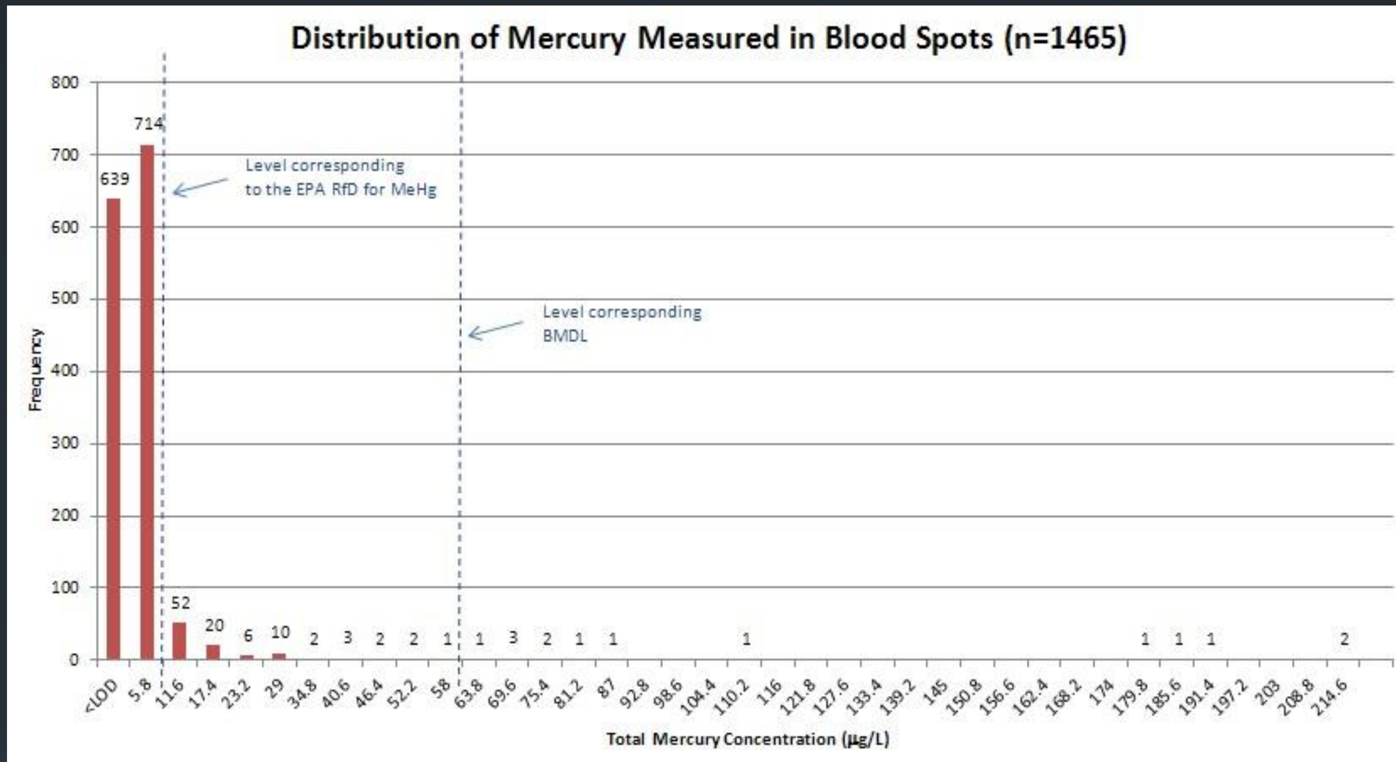
Rural/Urban (MN only)

- Rural 550 (49%)
- Urban 576 (51%)

McCann P. Mercury levels in blood from newborns in the Lake Superior Basin (GLNPO ID 2007-942). Final Report. November 30, 2011. Available at: www.health.state.mn.us/divs/eh/hazardous/topics/studies/glnpo.pdf.

Of the samples analyzed, 8% were above 5.8 µg/l, the US EPA Reference Dose (RfD) for methylmercury, and 1% were above the BMDL level of 58 µg/l.

Total mercury concentrations



Summary: wide range of results; 8% > 5.8 µg/l; 1% > 58 µg/l!

RfD = reference dose
BMDL = benchmark dose lower limit

McCann P. Mercury levels in blood from newborns in the Lake Superior Basin (GLNPO ID 2007-942). Final Report. November 30, 2011. Available at: www.health.state.mn.us/divs/eh/hazardous/topics/studies/glnpo.pdf.

Lasting Effects of Neuro-developmental and other health impairments

- Individual costs
- Community costs
- Healthcare costs

Summary points regarding potential toxicity:

- Heavy Metals with many harmful effects to human health: cancer, heart and lung disease, neurodevelopmental disorders
- Methylmercury exposure can occur by eating fish and other food sources contaminated via bioaccumulation and biomagnification within in the food chain
- Developing human brains are more susceptible
- Methylmercury has significant toxicity in humans
- MDH study demonstrated mercury as already existing problem
- Neurotoxic damage from methylmercury can have significant impacts on individuals and society
- Health impacts of mercury exposure could be disproportionate, affecting people consuming local fish at higher rates: a social, cultural and health justice issue

Review MAFP’s human health advocacy efforts: Focused concerns

Scale of many proposed copper-nickel sulfide mine projects

- 500 football fields 20 stories high of excavated rock now exposed to air and water
- Multiple mining companies likely to propose even larger mines to be developed in the water rich environment of northern Minnesota.

Length of time water will need to be either contained or treated

- Hundreds of years

History

- Never has a sulfide mine been developed, operated and closed without producing polluted drainage.

Analyses

- Kuipers et al (2006) studied 25 operating hard rock mines and their EISs: all predicted compliance with water quality standard within their EISs however pollution from 85% of mines near surface water and 93% of mines near ground water exceeded water quality standards. 89% had inaccurately predicted that they would not create AMD.
- Earthworks article studied fourteen operating copper mines representing 89% of the US copper production. 100% had pipeline spills or accidental releases.

Are existing regulatory agencies adequately protecting us?

Sulfide mines invariably produce polluted drainage from their operations despite their plans that predict that there will be no pollution.

The United States Environmental Protection Agency (US EPA)

- The USEPA is involved in the production and approval of Environmental Impact Statements and tasked with enforcing violations of Federal law
- Major violations are not uncommon
  - In situations (such as Superfund sites) the US EPA tries to hold those responsible for the cleanup liable for damage costs, however, they are often thwarted in this attempt
- Toxic release information

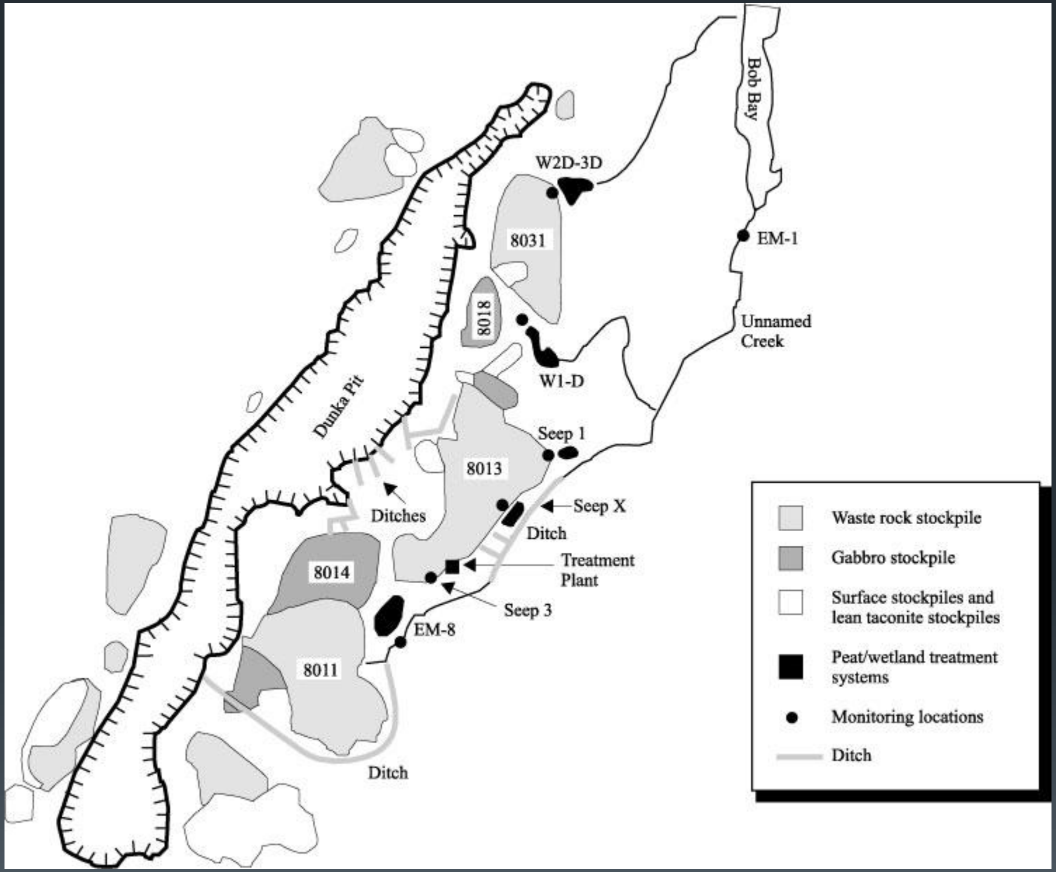
Are current regulatory agencies adequately protecting us?--continued

- Minnesota Pollution Control Agency (MPCA)
- The MPCA issues permits for actions related to the discharge of pollutants to surface waters. They must also certify compliance with state water standards
  - Variances
  - Inability to enforce regulations
  - Example: Dunka Mine (next slide)

Dunka Mine

Example of MN iron mine operation exposing a sulfide ore body with ongoing toxic runoff

- The Dunka pit is being considered by Twin Metals for use as a tailings disposal area
- This area was the location of an iron mining operation that exposed sulfide ore which produced acid drainage.
- For decades, the site has discharged heavy metals and acidic runoff into Birch Lake through an unnamed creek.
- There has been little action against those responsible and the runoff problem continues.



Source: Interstate Technology Regulatory Council
http://www.itrcweb.org/miningwaste-guidance/cs_dunka_mine.htm

Are Current Regulatory Bodies are Adequate to Protect us?

- Minnesota Department of Natural Resources (DNR)

  The Minnesota DNR grants mining permits but has a conflicting mission. On the one hand, they are tasked with investigating potential environmental consequences. On the other hand, they are tasked with promoting economic interests through the extraction of Minnesota's mineral resources.

- Minnesota Department of Health (MDH)

  This agency helps regulate groundwater quality through permitting processes related to water supplies and wells.

Public risk and ‘price tag’

Taxpayer Risk

- It is taxpayers who are left with large bills to pay for the cleanup of abandoned sulfide mines. (Superfund sites)
- US EPA estimates the cost of mine cleanup for sites listed as national priorities at $20 billion. The most significant cost for this is ling-term water treatment and management.
- Tailings dam failures result in devastating loss of livelihood and life

Acid mine drainage flows through a stream in western Pennsylvania. Photo by Nathaniel Warner.

Every sulfide mine (100%) in a water-rich environment has polluted surface and/or groundwater with acid mine drainage and/or toxic metals.

Regulatory Tools to evaluate health risks: HRA and HIA

HIA	HRA
▪ Focuses on the Social Determinants of Health ▪ Primarily qualitative ▪ Stakeholder engagement highly valued	▪ Focuses on specific contaminants/ hazards ▪ Primarily quantitative (deriving specific values) ▪ Expert-driven

* *Note: Both have systematic processes & are based on science.*

HIA – Health Impact Assessment; HRA – Health Risk Assessment

Why HIA?

- Identify harms and benefits *before decisions are made*
- Identify *evidence-based strategies* and recommendations to promote health and prevent disease
- Support *inclusive and democratic decision-making* and increase transparency in the decision-making process
- Support *community engagement* in the decision-making process and foster community empowerment
- Advance *equity and justice*

* *Note: There are many ways to insert health into decision-making. HIA is one way.*

Physician Advocacy for Health Impact Assessments

October 2016 MAFP members and leadership advocate for MAFP's request for a MN Rule change to require Health Risk and Health Impact Assessments as part of the Environmental Review process. Pictured, left to right: John Ipsen MD, Jennifer Pearson MD, Maria Huntley MAFP Executive Director, Dania Kamp MD MAFP 2016 President, Emily Onello MD, Deborah Allert MD, and Kristan Wegerson MD.

History of Healthcare Profession Involvement

- MPHA (October 2014): letter representing over 400 public health professionals.
- MN Nurses Association (March, 2014): letter representing over 20,000 nurses.
- Health Providers Letter (March, 2014): letter of 46 doctors and nurses.
- Individual Health Professionals letter (Oct. 2014): 94 individuals plus Healthy Food Action and Food and Water Watch for a total of 153 health professionals (October 2014).
- MMA (Sept. 25th, 2014): letter representing over 10,000 physician members
- Physician meetings with MN Dept. of Health (May 2014) and DNR officials (July 2014)

History of MAFP and Physician Involvement

MINNESOTA ACADEMY OF FAMILY PHYSICIANS
STRONG MEDICINE FOR MINNESOTA

- Lake Superior Chapter Minnesota Academy of Family Physicians April 2015 resolution to statewide MAFP requesting a Health Impact assessment be completed prior to permitting of PolyMet
- Resolution adopted *unanimously* at House of Delegates meeting and subsequent letter sent
- September 2015, nine physicians invited to meet with Commissioners of Health, MPCA, DNR and representatives from Governor Dayton's Office to advocate for HIA.

History of MAFP and physician involvement, continued

MINNESOTA ACADEMY OF FAMILY PHYSICIANS
STRONG MEDICINE FOR MINNESOTA

July 2016 meeting in Duluth MN between EQB leadership and MAFP members, MAFP 2016 president and MAFP Executive Director

- April 13th, 2016 MAFP House of Delegates passed a resolution asking for a rule change to Minnesota Administrative Rules, Chapter 4410 to require a comprehensive and independent HIA be prepared for all sulfide mining projects requiring and EAW or EIS.
- On May 25th, 2016, this petition was sent to the Minnesota Environmental Quality Board.
- July 19th, 2016 the Chair and staff of the EQB came to Duluth to discuss the MAFP petition.
- Oct. 19th 2016 members of the MAFP, including the current state president met with the EQB to further discuss the request for an HIA rule change

History of MAFP physician involvement, continued

October 2016 MAFP members and leadership advocate for MAFP's request for a MN Rule change to require Health Risk and Health Impact Assessments as part of the Environmental Review process. Pictured, left to right: John Ipsen MD, Jennifer Pearson MD, Maria Huntley MAFP Executive Director, Dania Kamp MD MAFP 2016 President, Emily Onello MD, Deborah Allert MD, and Kristan Wegerson MD.

To date, Environmental Quality Board has not ruled on MAFP's petition.

In 2026, discussions continue about rulemaking and legislation to support HIAs.

Published Articles:

Sulfide Mining and Human Health in Minnesota

BY EMILY ONELLO, MD, DEB ALLERT, MD, STEVE BAUER, MD, JOHN IPSEN, MD, PHD, MARGARET SARACINO, MD, KRIS WEGERSON, MD, DOUGLAS WENDLAND, MD, MPH, AND JENNIFER PEARSON, MD

Sulfide mining (specifically copper-nickel sulfide mining) represents a significant departure from Minnesota's iron mining tradition. Sulfide mining can produce acid waste and sulfates that mobilize the release of heavy metals into the environment. These metals include known neurotoxins such as lead and mercury. Mining activities also create airborne fibers and pollutants that can contribute to increased morbidity. The short- and long-term effects of exposure to these substances on human health should be considered in present and future sulfide mining proposals. In addition, Minnesota physicians need to understand the potential adverse mental and physical health effects of sulfide mining on mine workers and residents of communities near mining operations.

The Duluth Complex is a geological formation that contains deposits of copper, nickel and palladium group metals. It is located at the eastern end of the Mesabi Iron Range in northeastern Minnesota.[1] PolyMet Mining plans to build an open-pit mine in the northeastern part of the state to recover those valuable metals. Other mining companies are also exploring mineral deposits and preparing proposals for extracting them.

During the past three years, multiple organizations representing health care professionals have voiced concern about the potential effects of copper-nickel mining on human health. The Minnesota Medical Association, Minnesota Public Health Association, Minnesota Nurses Association and Minnesota Academy of Family Physicians have each endorsed deeper inquiry into the potential health effects of sulfide mining, and specifically of copper-nickel mining. Although the majority of debates about sulfide mining in our state have been framed as "environment versus jobs," the impact on human health needs to be a part of these discussions.

Sulfide mining has significant potential for the release of toxic chemicals into the environment. These include a number of chemicals identified by the World Health Organization as being of major public health concern: arsenic, asbestos, cadmium, lead and mercury.[2] Given this ominous list, and the possible synergistic effects of co-exposure to more than one of these chemicals, it is important that physicians understand why concerns are being raised about this type of mining.

FIGURE 1

Metal sulfide oxidation sequence using pyrite as an example

Pyrite (FeS_2) is exposed to air (O_2) and water (H_2O)

A sequence of reactions occur creating sulfate, ferric hydroxide and hydrogen ions.

Additional chemical reactions occur involving pyrite, iron sulfate and water, resulting in the release of sulfuric acid.

Sulfuric acid promotes release of other metals from rock and causes harm to aquatic ecosystems.

Source: Jacobs JA, Lehr JH, Testa SM. Acid Mine Drainage, Rock Drainage and Acid Sulfate Soils: Causes, Assessment, Prediction, Prevention and Remediation. Hoboken, NJ: John Wiley & Sons; 2014


HUMAN AND ECOLOGICAL RISK ASSESSMENT
https://doi.org/10.1080/10807039.2019.1576026
Taylor & Francis
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Check for updates

Risks and costs to human health of sulfide-ore mining near the Boundary Waters Canoe Area Wilderness

Jennifer Pearson[a], John Ipsen[b], Steven Sutherland[c,d,e], Kristan Wegerson[b], and Emily Onello[a]

[a]Department of Family Medicine and Biobehavioral Health, University of Minnesota Medical School, Duluth, MN, USA; [b]Family Practice, Bad River Health and Wellness Center, Ashland, WI, USA; [c]Child and Adolescent Psychiatry, Duluth, MN, USA; [d]Department of Psychiatry, Essentia Health, Duluth, MN, USA; [e]University of Minnesota Medical School, Duluth, MN, USA

ABSTRACT
Sulfide-ore copper nickel (SOCN) mining is being considered in water-rich Minnesota. Given pollution resulting from SOCN mining elsewhere, careful scrutiny is necessary examining the risks associated. Health considerations of mining within the Rainy River Watershed, the geographic region at the headwaters of the Boundary Waters Canoe Area Wilderness (BWCAW), Ontario's Quetico Park (Quetico), and Voyageurs National Park (VNP) are examined. This discussion considers toxins released from SOCN mining, examines data regarding degradation of water quality and deleterious environmental impact from SOCN mining elsewhere, considers the most vulnerable populations, and recognizes the broader effects to public health as well as benefits of existing wilderness. Recent federal decisions to reinstate mineral leases and abort the environmental assessment process have placed this unique and irreplaceable region of our country at substantial risk. The overall health and wellness of this region will very likely be negatively affected by SOCN mining, and economic costs will predictably outweigh benefits. In addition, negative impacts on water, fish and wild rice will likely degrade nutritional and tribal resources resulting in violation of usufructuary rights of tribal communities.

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KEYWORDS
sulfide-ore mining; health impact assessment (HIA); environmental toxins; environmental impact statement (EIS); mineral leases; acid mine drainage; Indigenous rights

Introduction

Minnesota is known as "the land of 10,000 lakes." The name comes from the native Ojibway (or Anishinaabe) language and translates to "land of sky-blue waters." The state lies at the head of three continental watersheds and shares its northeastern border with Lake Superior, which is estimated to contain 10 percent of the planet's freshwater (Minnesota Water Facts 2010). What Saudi Arabia is to oil, Minnesota is to freshwater. The Duluth Complex is a mineral deposit containing copper, nickel, and precious metals that lies within the Lake Superior and Hudson Bay Watersheds (NorthMet Mining Project and Land Exchange 2015). Active SOCN (also referred to as hard rock) mining is now being pursued in northern Minnesota, an area without any prior SOCN mining.

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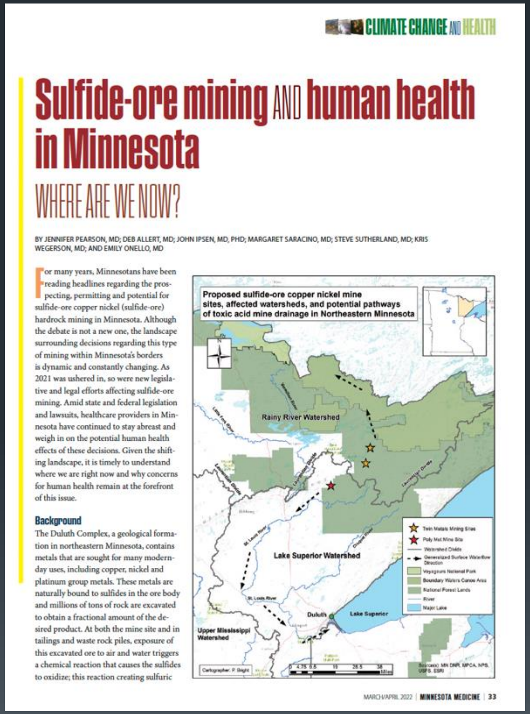

Sulfide-ore mining AND human health in Minnesota

WHERE ARE WE NOW?

BY JENNIFER PEARSON, MD; DEB ALLERT, MD; JOHN IPSEN, MD, PHD; MARGARET SARACINO, MD; STEVE SUTHERLAND, MD; KRIS WEGERSON, MD; AND EMILY ONELLO, MD

For many years, Minnesotans have been reading headlines regarding the prospecting, permitting and potential for sulfide-ore copper nickel (sulfide-ore) hardrock mining in Minnesota. Although the debate is not a new one, the landscape surrounding decisions regarding this type of mining within Minnesota's borders is dynamic and constantly changing. As 2021 was ushered in, so were new legislative and legal efforts affecting sulfide-ore mining. Amid state and federal legislation and lawsuits, healthcare providers in Minnesota have continued to stay abreast and weigh in on the potential human health effects of these decisions. Given the shifting landscape, it is timely to understand where we are right now and why concerns for human health remain at the forefront of this issue.

Background

The Duluth Complex, a geological formation in northeastern Minnesota, contains metals that are sought for many modern-day uses, including copper, nickel and platinum group metals. These metals are naturally bound to sulfides in the ore body and millions of tons of rock are excavated to obtain a fractional amount of the desired product. At both the mine site and in tailings and waste rock piles, exposure of this excavated ore to air and water triggers a chemical reaction that causes the sulfides to oxidize; this reaction creating sulfuric

Talon Nickel Mine – Threat to Mississippi River Watersheds

MASSIVE SULFIDE MINERALIZED ZONE

- About 50 miles west of Duluth.
- Nickel, cobalt, copper sulfide ore.
- Active mineral leases for 30,000 acres.
- Underground mine, waste storage, processing metals.

WATER RESOURCES AT RISK

- Headwaters of Kettle River, which flows into the St. Croix River. Both are Wild and Scenic.
- Headwaters of Tamarack River, which flows to the Mississippi River.
- Abundant wild rice lakes, important Tribal resources.
- Groundwater used for drinking water.

Slide courtesy of WaterLegacy

Changing times

- Rollbacks on clean water and mining regulations
- Fewer environmental protections
- It is more important than ever for physicians to be the voice of the community

Making a Difference

- Be involved
- Be informed
- Be willing to use your resources and partner with others
- Be an educator of public officials
- Be willing to leverage your history of caring for your community
- Most of all, be willing to stand up and speak out

Thank you

- To the MAFP for this opportunity to talk to you

- To my colleagues:
  - Jennifer Pearson MD
  - Deb Allert MD
  - Kris Wegerson MD
  - John Ipsen MD
  - Steve Bauer MD
  - Margaret Sarascino MD
  - Susan Nordin MD
  - Steve Sutherland MD

- And to Paula Maccabee, Esq. & Sophia Patane

AI/LLM Disclosure

The author’s disclosure of AI (artificial intelligence) or LLM (large language model) is as follows:

The text within this presentation was generated by the author with the exception is the slide titled “Key mechanisms of Neurotoxicity of Hg” which used language from Google Gemini’s AI search feature (2026).

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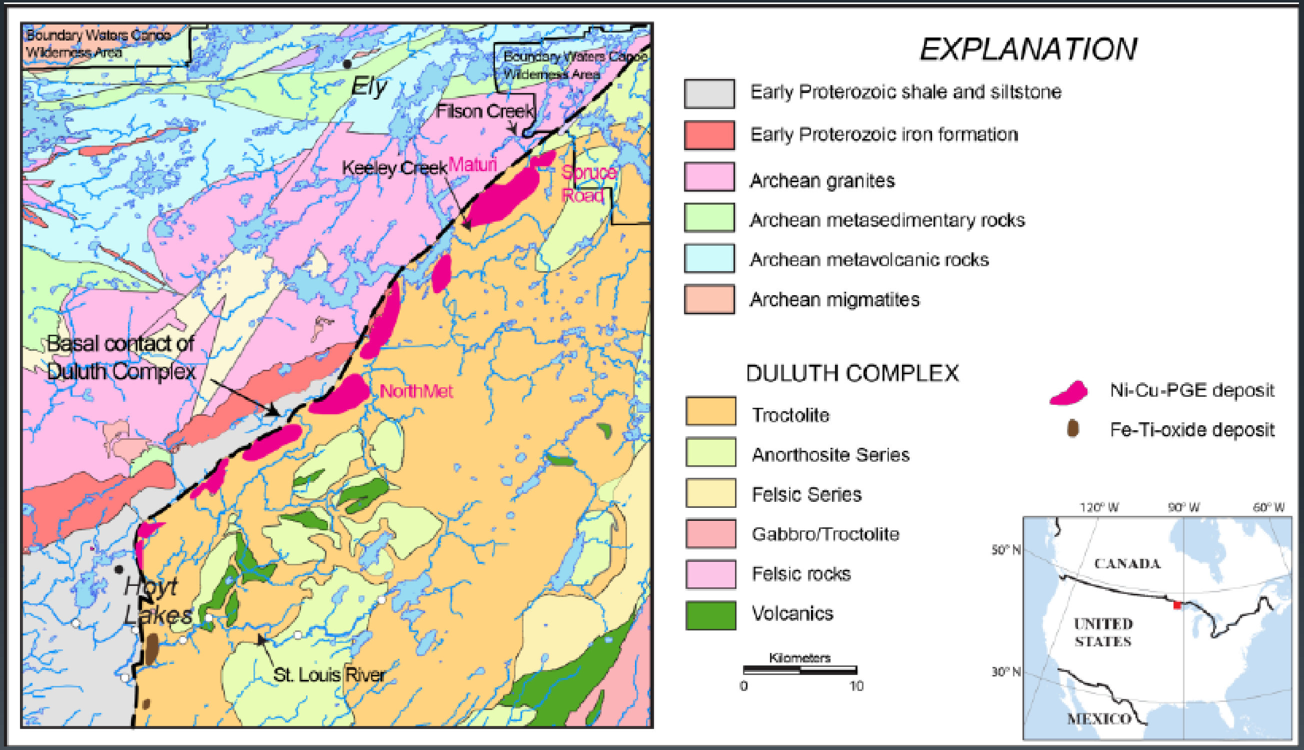
Questions?



Boundary Waters Canoe Wilderness Area
Boundary Waters Canoe Wilderness Area
Ely
Filson Creek
Keeley Creek
Maturi
Spruce Road
Basal contact of Duluth Complex
NorthMet
Hoyt Lakes
St. Louis River
EXPLANATION
Early Proterozoic shale and siltstone
Early Proterozoic iron formation
Archean granites
Archean metasedimentary rocks
Archean metavolcanic rocks
Archean migmatites
DULUTH COMPLEX
Troctolite
Anorthosite Series
Felsic Series
Gabbro/Troctolite
Felsic rocks
Volcanics
Ni-Cu-PGE deposit
Fe-Ti-oxide deposit
Kilometers
0
10
120° W
90° W
60° W
50° N
30° N
CANADA
UNITED STATES
MEXICO

Thank you for your attention today.

Please contact me with comments or questions.

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