

Boundary Waters Canoe Area Wilderness
Superior National Forest Withdrawal EIS
Outline of Materials Delivered to USFS and BLM on August 17, 2017
Updated October 12, 2017

See also Appendix of Reports and Other Materials Delivered for the Scoping Phase of the Withdrawal EIS
for the Superior National Forest (Appendix Scoping Deliveries)

1. Scientific Resources

a. Summaries and Fact Sheets

- i. "The Science" Updated October 2017 – Bullet points from scientific reports conducted specifically to examine the Boundary Waters ecosystem and risks from sulfide-ore copper mining and relevant scientific and economic studies describing the Boundary Waters Canoe Area Wilderness ("Boundary Waters") ecosystem and threats from sulfide-ore copper mining
- ii. "Science to Date dated April 2017" – Annotated bibliography of relevant scientific and economic studies describing the Boundary Waters Canoe Area Wilderness ecosystem and threats from sulfide-ore copper mining
- iii. "Environmental Risk to the Boundary Waters Region" – Narrative case statement of risks to Boundary Waters ecosystem from sulfide-ore copper mining
- iv. "Endangered Species Threatened by Proposed Sulfide-Ore Copper Mining in Boundary Waters Watershed"
- v. "Estimated Climate Impacts of Proposed Twin Metals Minnesota Mine" – Fact sheet containing calculations showing the possible carbon contributions to the atmosphere as a result of the proposed Twin Metals Minnesota Mine
- vi. "A Watershed Moment: Findings from Potential Metals Mining and Voyageurs National Park" – Summary of a hydrological study investigating risk to Voyageurs National Park from sulfide-ore copper mining
- vii. "So-Called 'Clean Mining' Still Unproven and Dangerous: Why Pyrite Flotation Won't Protect the Boundary Waters"

b. Reports Specific to the Boundary Waters Ecosystem and Sulfide-Ore Copper Mining

- i. "Technical Memorandum: Twin Metals Mining and the Boundary Waters Canoe Area Wilderness, Risk Assessment for Underground Metals Mining, Phase I" (2013) – Dr. Tom Myers, hydrologist
- ii. "Technical Memorandum: Twin Metals Mining and the Boundary Waters Canoe Area Wilderness, Risk Assessment for Underground Metals Mining, Phase II" (2014) – Dr. Tom Myers, hydrologist
- iii. "Technical Memorandum: Potential Metals Mining and the Voyageurs National Park Risk Assessment for Upstream Metals Mining" (2015) – Dr. Tom Myers, hydrologist
- iv. "Acid Mine Drainage Risks – A Modeling Approach to Siting Mine Facilities in Northern Minnesota USA" *Journal of Hydrology* 533: 277-290 (2016) – Dr. Tom Myers, hydrologist
- v. "Twin Metals Mine and the Peter Mitchell Pit, Simulation of the Development of the Peter Mitchell Pit and Its Effects on the Proposed Twin Metals Tailings Impoundment" (2016) – Dr. Tom Myers, hydrologist
- vi. "Potential Ecological Impacts of the Twin Metals Mine" – Dr. Larry Baker, applied ecologist and environmental engineer

- vii. "Scoping Comment Letter Re: Northern Minnesota Federal Mineral Withdrawal EIS #50938" (2017) – Dr. Daniel Engstrom, one of the lead scientists studying the effects of sulfate on mercury cycling, wild rice, and sulfur biogeochemistry in Minnesota
 - viii. "The Fish and Fisheries of the Boundary Waters Canoe Area Wilderness and Voyageurs National Park, and Their Vulnerability to Copper Sulfide Mining" (2017) – Dr. Paul Venturelli and Dr. Bruce Vondracek, fisheries biologists
 - ix. "Forest and Terrestrial Ecosystem Impacts of Mining" (2014) – Dr. Lee Frelich, forest ecologist
 - x. Letter from Dr. Lee Frelich dated February 19, 2014 concerning the international significance of the Boundary Waters as a baseline
 - xi. "Mammals and Mining for Minerals in Sulfur-Bearing Rock Formations in Northeastern Minnesota" (2017) – Dr. Roger Powell, applied ecologist
 - xii. "Birds of Minnesota's Boundary Waters Canoe Area and Adjacent Upstream Regions, with Comments on Conservation Implications of New Copper Mining Under Consideration" (2017) – Dr. John Fitzpatrick, ornithologist
 - xiii. "The Potential for Acid Mine Drainage and Other Water Quality Problems at Modern Copper Mines Using State-of-the Art Prevention, Treatment, and Mitigation Methods" (2014) – Dr. David Chambers, professional engineer
 - xiv. "Cumulative Effects Analysis on Wildlife Habitat Loss/Fragmentation and Wildlife Travel Corridor Obstruction/Landscape Barriers in the Mesabi Iron Range and Arrowhead Regions of Minnesota" (2006) – Emmons and Olivier Resources, Inc., prepared for Minnesota Department of Natural Resources
 - xv. "Technical Document: *Acid Mine Drainage Prediction*" Tech. no. EPA530-R-94-036. Washington D.C.: Environmental Protection Agency, December 1994. NTIS No. PB94-201829. (Referring to 'The Acid-Generating Duluth Complex')
 - xvi. "An Evaluation of a Field-Based Aquatic Life Benchmark for Specific Conductance in Northeast Minnesota" (2015) – B. Johnson, biologist and chemist, and M. Johnson, biologist
 - xvii. "Review of 'An Evaluation of a Field-Based Aquatic Life Benchmark for Specific Conductance in Northeast Minnesota'" (2016) – Dr. Susan Cormier, Office of Research and Development, U.S. EPA
 - xviii. See Reports Referenced in the Appendix of Scoping Deliveries:
 - 1. Water - Water Quality Data Tables
 - 2. Water - Water Monitoring Reports
 - 3. Water - Sulfate & Wild Rice
 - 4. Water - Fisheries and Aquatic Resources Reports
 - 5. Wildlife & Terrestrial Habitats – Scientific Studies
 - 6. Wildlife & Terrestrial Habitats – Maps
 - 7. Climatological Information & Projections for More Extreme Rain Events
- c. Supporting Studies
- i. "Minnesota Regional Copper-Nickel Study: Bibliography of Technical Reports" – Minnesota Environmental Quality Board – The Regional Copper-Nickel Study was "commissioned because it was believed that conventional site-specific environmental impact statements (EIS's) and the corresponding regulatory process were inadequate to deal with the broader issues involving this unexploited resource" (Executive Summary, p. I), and over 180 original technical reports were conducted by Environmental Quality Board staff and other experts

- ii. The Sulfide-Ore Copper Mining Industry's Track Record of Environmental Impacts
1. "US Copper Porphyry Mines Report: The Track Record of Water Quality Impacts Resulting from Pipeline Spills, Tailings Failures and Water Collection and Treatment Failures" (2012) – Earthworks
 2. "COPPER SULFIDE MINING: The Track Record of Waters Quality Impacts Resulting From Pipeline Spills, Tailings Failures and Water Collection and Treatment Failures" Fact sheet (2015) - Earthworks
 3. "Predicting Water Quality Problems at Hardrock Mines: A Failure of Science, Oversight, and Good Practice" (2006) – Earthworks
 4. "U.S. Gold Mines Spills and Failures Report: The Track Record of Environmental Impacts Resulting from Pipeline Spills, Accidental Releases and Failure to Capture and Treat Mine Impacted Waters" (2017) – Earthworks
 5. "False Promises: Water Quality Predictions Gone Wrong Large Mines and Water Pollution" (2004) – Earthworks
 6. "Evaluation Report: Nationwide Identification of Hardrock Mining Sites" (2004) – Environmental Protection Agency, Office of Inspector General
 7. "Comparison of Predicted and Actual Water Quality at Hardrock Mines: The Reliability of Predictions in Environmental Impact Statements" (2006) – James Kuipers, mining engineer, and Dr. Ann Maest, aqueous geochemist
 8. "Predicting Water Quality at Hardrock Mines; Methods and Models, Uncertainties and State-of-the-Art" (2005) – James Kuipers, mining engineer, and Dr. Ann Maest, aqueous geochemist
 9. "Long-term Risk of Tailings Dam Failure" (2014) – Dr. David Chambers
 10. "The Risk, Public Liability, & Economics of Storage Facility Failures" (2011) – Lindsay Newland Booker, CPCU, ARM, and Dr. David Chambers, professional engineer
 11. "The Impact of a Catastrophic Mine Tailings Impoundment Spill into One of North America's Largest Fjord Lakes: Quesnel Lake, British Columbia, Canada" (2015) – Petticrew, E. L., et al.
 12. "A Review of the 'Report on Mount Polley Tailings Storage Facility Breach, Independent Expert Engineering Investigation and Review Panel'" – Dr. David Chambers, professional engineer
 13. "Dam Breach at Mount Polley Mine in British Columbia" (2014) – Jesse Allen and Adam Voiland
 14. "Dam Safety Review, Mount Polley Mine, Likely, British Columbia" (2006) – AMEC Earth & Environmental Limited
 15. "Long Term Risks of Tailings Dam Failure" – Dr. David Chambers, professional engineer, & Brentwood Higman
 16. "Wisconsin Resources Protection Council, Center for Biological Diversity, and Laura Gauger v. Flambeau Mining Company, Case No. 11-cv-45, Supplemental Expert Report" (2012) – Dr. David Chambers, professional engineer
 17. "EPA Region 5 'Approval Letter of Wisconsin's 2012 303(d) List'" – Letter to Russell Rasmussen, Division of Waters, Wisconsin DNR, June 25, 2014

18. "SUMMARY: Flambeau Mine: Water Contamination and Selective Alternative Facts" (2017) – Robert Moran, PhD
19. "Wisconsin DNR 'Reclaimed Flambeau Mine'" (2017) Wisconsin DNR
20. "Dunka Pit NPDES/SHS Permit Inconsistencies with Federal and State Law" Letter to Commissioner Paul Aasen, MPCA dated March 11, 2011
21. "The Lesson of Dunka" - *The Timberjay* (Oct. 14, 2015)
22. "Mining vs. Water: Dunka site exposes breakdown in mine regulation"– *The Timberjay* (Oct. 7, 2015)
23. SEC Filings: Stillwater Mining Company ANNUAL REPORT PURSUANT TO SECTION 13 OR 15(d) OF THE SECURITIES EXCHANGE ACT OF 1934 FOR THE FISCAL YEAR ENDED DECEMBER 31, 2016, Form 10-K
24. SEC Filings: Stillwater Mining Company ANNUAL REPORT PURSUANT TO SECTION 13 OR 15(d) OF THE SECURITIES EXCHANGE ACT OF 1934 FOR THE FISCAL YEAR ENDED DECEMBER 31, 2010, Form 10-K
25. "Evaluation of Static and Kinetic Prediction Test Data and Comparison with Field Monitoring Data" – Elizabeth Sherlock, mining and mineral engineering masters candidate
26. "Reported Tailings Dam Failures: A Review of the European Incidents in the Worldwide Context" (2008) – Rico, M., et al.
27. "Conflicts Over Water in Chile: Between Human Rights and Market Rules (2011) – Sara Larrain and Columбина Shaeffer
28. "Mine Waste Management in the 21st Century: Challenges & Solutions Beyond Incremental Changes" (2011) - Andrew MacGregor Robertson, Robertson GeoConsultants
29. "Durability of HDPE geomembranes" (2002) - R. Kerry Rowe and Henri P. Sangam
30. "Polluting the Future: How Mining Companies are Contaminating Our Nation's Waters in Perpetuity" (2013) – Lisa Sumi and Bonnie Gestring
31. The Center for Science in Public Participation "SCP2 Fact Sheets: Arsenic, Cadmium, Copper, Cyanide, Lead, Mercury, Selenium, Zinc"
32. "Memorandum in Support of the Minnesota Center for Environmental Advocacy's Petition for Rulemaking on Anti-Degradation" (2005) - Minnesota Center for Environmental Advocacy
33. "Minnesota Center for Environmental Advocacy's Petition For Corrective Action or Withdrawal of NPDES Program Delegation From the State of Minnesota" Letter to Lisa Jackson, EPA Administrator, and Bharat Mathur, Acting Regional Administrator dated October 5, 2009 – Minnesota Center for Environmental Advocacy
34. "WaterLegacy Petition for Withdrawal of Program Delegation from the State of Minnesota for NPDES Permits Related to Mining Facilities" (2015) – WaterLegacy petition to US Environmental Protection Agency in light of Minnesota's failure to administer the National Pollution Discharge Elimination System program in accordance with the Clean Water Act and EPA regulations regarding mining projects
35. "Citing MPCA Weakness, Group Asks Feds to Step in on Mining's Water Pollution" (2015) – Ron Meador, MinnPost
36. "Group Asks EPA to Regulate State's Mining Industry"– *The Timberjay* (July 8, 2015)

37. "Regulating Mining: Petition Reveals a State Government Captured by a Major Industry" – *The Timberjay* (July 8, 2015)
 38. "EPA Raises More Concerns Over Lack of Pollution Oversight" – *The Timberjay* (2016)
 39. "Mining Regulation? Legislature Shows a Lack of Will" – *The Timberjay* (June 1, 2016)
 40. "EPA to Look at Enforcement Allegations" – *The Timberjay* (2016)
 41. "Will Sulfate Standard Changes Matter?" – *The Timberjay* (2015)
 42. "U.S. Steel Goes to Court Against Minnesota over Minntac Permit" – *Minnesota Public Radio* (2017)
 43. "Minnesota Pollution Regulators Propose for First Time Deadlines for Minntac Tailings Basin to Meet Goals" – Josephine Marcotty, *StarTribune* (2016)
 44. "EPA Presses Minnesota Over Laws Exempting Taconite Firms from Wild Rice Rules" – Josephine Marcotty, *StarTribune* (2016)
 45. "Minnesota PCA Accused of Allowing Lake Pollution" – Josephine Marcotty, *StarTribune* (2012)
 46. "MPCA Proposed Minntac Permit" – *The Timberjay* (2016)
- iii. Impacts on Fish Ecology and Health from Sulfide-Ore Copper Mining
1. "Characterizing Coal and Mineral Mines as a Regional Source of Stress to Stream Fish Assemblages" (2014) – Daniel, W.M., et al.
 2. "Acid Mine Drainage and Effects on Fish Health and Ecology: A Review" (2008) – Reclamation Research Group, LLC
 3. "Macroinvertebrate Community Structure as an Indicator of Acid Mine Pollution" (1974) – Dills, G., and D.T. Rogers Jr
 4. "Effect of Mine Tailings on the In Situ Survival of Walleye (*Stizostedion vitreus*) Eggs in a Northern Ontario River" (1994) – Leis, A.L., and M.G. Fox
 5. "Feeding, Growth, and Habitat Associations of you-of-Year Walleye (*Stizostedion vitreus*) in a River Affected by a Mine Tailings Spill" – (1996) Leis, A.L., and M.G. Fox
 6. "Effects of Environmental Methylmercury on the Health of Wild Birds, Mammals, and Fish" (2007) – Scheuhammer, A.M., et al.
 7. "Impact of Heavy Metals on Insect Communities in Streams: A Comparison of Observational and Experimental Result" (1988) – W.H. Clements, D.S. Cherry, and J. Cairns
 8. "AFS Position Paper and Policy on Mining and Fossil Fuel Extraction" (2016) – R. M. Hughes, F. Amezcua, D.M.Chambers, W.M. Daniel, J.S. Franks, W. Franzin, D. MacDonald
 9. "The Toxicity of Heavy Metals, Beneficiation Reagents and Hydrogen Iodide to Aquatic Organisms" (1978) – David Lind, Theodore Halpern, and Mark D. Johnson
 10. "Downstream Effects of Mine Effluent on an Intermontane Riparian System" (1991) – J.N. Moore, N. Luoma, and D. Peters
 11. "Diel Mercury-concentration variations in streams affected by mining and geothermal discharge" *Science of the Total Environment* (2007) – David A. Nimick, Blaine R. McCleskey, Christopher H. Gammons, Thomas E. Cleasby and Stephen R. Parker

12. "Figures: Lead; SO₄; CU in the Category 1 Waste Rock Stockpile Drainage, etc. with and without modeled Climate Change" – Northmet Project Modeling Data Package 1.2 (2013)
 13. "Assessing Effects of Metal Mining Effluent on Fathead Meannow (*Pimephales Promelas*) Reproduction in a Trophic-Transfer Exposure System" *Environmental Science & Technology* (2006) – Carrie J. Rickwood, Monique G. Dube, Lynn P. Weber, Limberlea L. Driedger, and David M. Janz
 14. "Alternation of Fish Communities in Lakes Stressed by Acid Deposition and Heavy Metals near Wawa, Ontario" *Canadian Journal of Fisheries and Aquatic Sciences* (1984) – Keith M. Somers and Harold H. Harvey
 15. "Liquid Assets 2000: America's Water Resources at a Turning Point" (2000) – U.S. EPA
- iv. Impacts on Wildlife and Terrestrial Habitats from Sulfide-Ore Copper Mining
1. Loons are currently negatively impacted by environmental mercury:
 - a. "The Canadian Lakes Loon Survey: 32 Years of Monitoring Common Loons as Indicators of Ecosystem Health (Summary)" – Bird Studies Canada and the Canadian Lakes Loon Study
 - b. "Common Loon Reproductive Success in Canada: the West is the Best but Not for Long" – Tower, D.C., et al. (2013)
 2. Northeastern Minnesota's moose face significant stress and are already experiencing a population decline, and have been petitioned to be considered under the Endangered Species Act:
 - a. "Minnesota's Moose Numbers Drop Again: DNR Says Decline Will Likely Continue" – Paul Walsh, *Star Tribune*
 - b. "Groups File Petition to Classify Moose as Endangered Species" – Joe Albert, *Outdoor News*
 - c. Natural Resources Research Institute. "Moose in Minnesota: Public Pictures and Sightings." [sightings from 2009 to 2-15-2013] 2013
 3. Northeastern Minnesota offers designated critical habitat for the Canada lynx, a threatened species under the Endangered Species Act:
 - a. "News Release: Service Revises Critical Habitat Designation for Canada Lynx Under Endangered Species Act" – US Fish and Wildlife Service Mountain-Prairie Region
 - b. Map: "Critical Habitat for *Lynx canadensis* (Canada Lynx), Unit 2 – Minnesota"
 - c. "Movement and Habitat Use of Canada Lynx During Denning in Minnesota" (Sept. 2008): 1507-1513. DOI: 10.2193/2008-072 – Ron Moen, et al.
 4. Minnesota's St. Louis and Cook Counties are home to hibernation and roost trees of the northern long-ear bat (*Myotis septentrionalis*), which was listed as threatened under the Endangered Species Act in January 2015:
 - a. "Northern Long-Eared Bat (*Myotis septentrionalis*)" – US Fish and Wildlife Service
 - b. "Townships Containing Long-Eared Bat Roost Trees and/or Hibernacula" – Minnesota DNR and US Fish and Wildlife Service:

- T62N R11W in Lake County contains one or more roost tree in addition to active sulfide-ore copper prospecting activity
5. Northeastern Minnesota is home to a gray wolf population under court order to be re-listed as threatened under the Endangered Species Act:
 - a. "Gray Wolf (*Canis lupus*)" – US Fish and Wildlife Service
 - d. Reports, Fact Sheets, Media Stories, and Letters on Human Health Impacts to the Boundary Waters Region of Sulfide-Ore Copper Mining
 - i. "Sulfide Mining and Human Health in Minnesota" *Minnesota Medicine* 2016 (6) 51-22 (2016) – Dr. E. Onello, M.D., et al., medical doctors
 - ii. Scoping Comment Letter Re: Northern Minnesota Federal Mineral Withdrawal EIS #50938" dated May 8, 2017 – signed by 111 Minnesota physicians and allied healthcare professionals, medical students, scientists, and groups
 - iii. "Mercury Levels in Blood from Newborns in the Lake Superior Basin" Final Report, Patricia McCann, Minnesota Department of Health Division of Environmental Health (2011)
 - iv. "Final Report: Methylmercury Sources to Lakes in Forested Watershed: Has Enhanced Methylation Increased Mercury in Fish Relative to Atmospheric Deposition?" (2002) – Edward Swain, et al.
 - v. "Public Health and Economic Consequences of Methyl Mercury Toxicity to the Developing Brain" (2005) - Leonardo Trasande, et al. *Environmental Health Perspectives*
 - vi. "Preventing Disease Through Healthy Environments: Action is Needed on Chemicals of Major Public Health Concern" (2010) – World Health Organization
 - vii. EPA Scoping Comment Letter for Proposed Withdrawal of Federal Minerals from Mineral Exploration and Development in Portions of the Rainy River Watershed, Lake and Saint Louis Counties, Minnesota – 4-6-2017
 - viii. Letter to Minnesota Congressional Delegation from 35 Rochester Area Physicians dated May 5, 2016
 - ix. "We must work to protect the Boundary Waters" – Dr. Jeffrey Rome, *Post Bulletin*, January 3, 2017
 - x. "Risks to Human Health from Sulfide-Ore Copper Mining" Factsheet dated October 2017
 - xi. "Healing in the wilderness; Military veterans look to protect the BWCAW for peace of mind, mental health advantages" - *The Timberjay* (Mar. 29, 2017)
 2. Economic Resources
 - a. Summaries, Factsheets, and News Stories About Reports
 - i. "Copper Mining in the BWCA Watershed: Minnesota's Arrowhead Region Has Far More to Lose Than Gain" - Fact sheet summarizing key findings of Key-Log Economics study of 2017
 - ii. "Study: Copper mining would have economic costs" – *The Timberjay* (Jul. 19, 2017)
 - iii. "Twin Metals Minnesota Mine: A Case Study in the Economic Costs of Sulfide-Ore Copper Mining" – Fact sheet summarizing an economic analysis published by *The Timberjay* (Aug. 3, 2017)
 - iv. "Ely's Golden Goose; Township residents power Ely-area economy" – *The Timberjay* (Jul. 3, 2017)
 - v. Township Impact; In copper nickel debate, we all should consider economic costs as well as gains" – *The Timberjay* (August 3, 2017)

- vi. "Twin Metals: Risks vs. Benefit" - Summary of Presentation by Marshall Helmberger (Sept. 2017)
- vii. "Surveys Show: People Choose Ely for the Boundary Waters" – Summary of a demographic survey of property owners in the Ely area conducted by the Center for Small Towns at the University of Minnesota, Morris
- viii. "Proposed Federal Land Withdrawal Does Not Affect Taconite Mining" – Factsheet explaining that the federal lands withdrawal study area does not affect any taconite mines
- ix. "THE ECONOMICS: The State of Minnesota is relying on a fatally flawed economic impact analysis to support sulfide-ore mining in Northeastern Minnesota" – A summary of the report "A Review of 'The economic impact of ferrous and non-ferrous mining on the State of Minnesota and the Arrowhead Region'" (2013)
- x. "Skurla's 'mining boom' due almost entirely to taconite" – *The Timberjay* (Feb. 27, 2014)
- xi. "Ely's economic renaissance warming up this sprint; Renovations of vacant buildings lead to new business ventures" – *The Timberjay* (Mar. 6, 2017)
- xii. "Tourism study: Analysis missed the way that tourism really builds a vibrant community" – *The Timberjay* (Mar. 1, 2017)
- xiii. "Study: BWCAW an economic boost" – *The Timberjay* (Feb. 16, 2017)
- xiv. "Twin Metals decision; We've had enough hyperbole; let's get to work building a diverse and stable economy" – *The Timberjay* (Dec. 22, 2016)
- xv. "Too many misunderstand the true impact of tourism" – *The Timberjay* (Aug. 10, 2016)
- xvi. "A real voice for Ely; Communities that rely on base metal mining have little say over their future" – *The Timberjay* (Jun. 30, 2016)
- xvii. "Report: VNP contributes \$25 million to area economy" – *The Timberjay* (Apr. 26, 2017)
- xviii. "Mining Minnesota study misfires on tourism" – *The Timberjay* (Apr. 26, 2017)
- xix. "Minnesota Congressional District 8 Fishing Impacts" (2011) – American Sportfishing Association
- xx. Four-page Boundary Waters Business Coalition Fact sheet with aerial photo of Birch Lake and 30 impacted businesses – May 1, 2017
- xxi. "Minnesota - The Outdoor Recreation Economy" – Outdoor Industry Association fact sheet detailing the contribution of the outdoor recreation industry to Minnesota economic health
- xxii. "Sportsmen: Sulfide Mining Puts Jobs/Economy at Risk" By David Lien, *Grand Rapids Herald-Review* (May 17, 2017)
- xxiii. "A little boosterism can go a long way in a small town" - *The Timberjay* (Oct. 5, 2016)
- xxiv. "Twin Metals fight: It's time for Ely to refocus on sustainable economic development" - *The Timberjay* (Mar. 9, 2016)
- xxv. "Rethinking 'the Range' One size shouldn't fit all when it comes to the area's economic future") - *The Timberjay* (Apr. 6, 2016)
- xxvi. "Ely dying? The numbers tell a far different story" – *The Timberjay* (Oct. 21, 2015)
- xxvii. "BLM Officials hear competing visions of the future") – *The Timberjay* (Nov. 18, 2015)

- xxviii. "Ely school enrollment jumps sharply" (Sept. 17, 2015) – *The Timberjay* (Sept. 17, 2015)
- xxix. "Iron Range: Why profits over people; Northern Minnesota legislators are doing the bidding of mining companies now" - By Marshall Helmberger *StarTribune* (Feb. 25, 2015)
- xxx. "Falling behind: Value of production tax erodes even as ore values skyrocket" – *The Timberjay* (Jan. 16, 2014)
- xxxi. "Why Business, Manufacturing, and Wilderness Thrive Together in Minnesota" – Factsheet on how the Boundary Waters helps make Minnesota a great place to do business
- xxxii. "Ely, Minnesota: Gateway to the Wilderness-Or Mining Town?" – Factsheet comparing the main economic drivers of Ely, Minnesota, and the natural amenities upon which they rely with claims that its economy relies on mining
- xxxiii. "Ely's Sue Schurke is Bringing Anoraks Back" – Candace Renalls, *Duluth News Tribune*
- xxxiv. "Steger Mukluks Expanding Production" – Iron Range Resources & Rehabilitation Board, *The Ranger*
- xxxv. "For Wenonah Canoe founder, inspiration started early") – *StarTribune* (Aug. 10, 2017)
- xxxvi. "Passing it on: Third generation of Hansen family outfitting canoeists at Sawbill" – Sam Cook, *Duluth News Tribune* (Aug. 19, 2017)
- b. Reports Demonstrating the Regional Economy and Economic Risk Posed by Sulfide-Ore Copper Mining
 - i. "Sulfide-Ore Copper Mining and/or A Sustainable Boundary Waters Economy: the Need to Consider Real Tradeoffs" (2017) – Dr. Spencer Phillips and Dr. Carolyn Alkire, natural resource economists/ Key-Log Economics, LLC
 - ii. "The Boundary Waters Canoe Area – Wealth Generator" (2015) – Dr. Spencer Phillips, natural resource economist/ Key-Log Economics, LLC
 - iii. "Literature Review: Impacts of Hard Rock Mining" (2014) – Bonnie Pascal/ Key-Log Economics, LLC
 - iv. "A Review of 'The economic impact of ferrous and non-ferrous mining in the state of Minnesota and the Arrowhead Region'" (2013) – Dr. Evan Hjerpe and Dr. Spencer Phillips
 - v. "Regional Economic Impacts of Boundary Waters Wilderness Visitors" (2017) – Dr. Evan Hjerpe/ Conservation Economics Institute
 - vi. "2014 National Park Visitor Spending effects: Economic Contributions to Local Communities, States, and the Nation" (2015) - National Park Service
 - vii. "Tourism to Voyageurs National Park Creates \$24,601,600 in Economic Benefits" (2017) – National Park Service
 - viii. "A Profile of Socioeconomic Measures of St. Louis, Lake, and Cook Counties" (2017) Economic Profile System (Headwaters Economics, Bureau of Land Management & U.S. Forest Service)
 - ix. "The Four Townships Area Economic, Housing and Development Survey" (2014) – Center for Small Towns and Data Services Center, University of Minnesota, Morris
 - x. "The Economic Role of Metal Mining in Minnesota: Past, Present, and Future" (2007) – Dr. Thomas Power, natural resources and economic development economist

- xi. "Northeastern Minnesota jobs, businesses, economy boosted by impact of tourism industry" (2011) – Iron Range Resource and Rehabilitation Board
 - xii. "Mining a Mirage? Reassessing the shared-value paradigm in light of the technological advances in the mining sector" (2016) - Aaron Cosbey, Howard Mann, Nicolas Maennling, Perrine Toledano, Jeff Geipel, and Martin Dietrich Brauch
 - xiii. "Northeast Minnesota: New Possibilities in the North Country" (2016) – Jay Walljasper/ The McKnight Foundation
 - xiv. "Recreational Demand for Clean Water: Evidence from Geotagged Photographs by Visitors to Lakes" (2015) – Keeler, B.L., et al., (2015)
 - xv. "Natural Amenities and Population Growth in the Greater Yellowstone Region" – Ray Rasker and Andrew Hansen, *Human Ecology Review* 7, n. 2; (2000): 30-40
 - xvi. "Next Level Mining" White Paper by ABB Group ("skeleton on-site workforce")
3. Wilderness Character and Impact Resources
- a. Reports Demonstrating Benefits of Maintaining Wilderness Characteristics and Risks from Sulfide-Ore Copper Mining
 - i. "The Impacts of Mining on the Character of a Landscape: Considering the Character of the Boundary Waters Canoe Area Wilderness and Adjacent Recreational Waterways in Federal Decision-Making" (2015) - Jane Reyer and Rachel Garwin - This synthesis report describing the human benefits of wilderness and the potential for negative impact on wilderness character from sulfide-ore copper mining activities outside the wilderness boundary
 - ii. "Improvements to the BWCAW Wilderness Character Since 1996" (2014) – Kevin Proescholdt - Summary of current wilderness character of the Boundary Waters Canoe Area Wilderness and the improvements to wilderness character made by intentional policy action at the federal and state level
 - iii. "Wilderness Benefits: A State-of-Knowledge Review" – Driver, B.L., et al. (1987) – Report by expert wilderness character and benefits scholars summarizing and categorizing the world of benefits people derive directly or indirectly from the existence of wilderness
 - iv. "The Effects of Wilderness Settings on Organized Groups: A State-of-Knowledge Paper" (2000) – Ewart, A., and L. McAvoy – Updated state-of-knowledge report on the benefits of wilderness experiences when used by group-sponsored programs
 - v. "Benefits of Nonfacilitated Uses of Wilderness" – Roggenbudck, J.W., and B.L. Driver (2000) – Updated state-of-knowledge review of benefits of non-facilitated wilderness experiences (i.e., not part of a group-sponsored program)
 - vi. "Veterans and the Outward Bound Experience: An Evaluation of Impact and Meaning" – Harper, N.J., et al. (2014) – Journal article detailing the benefits of wilderness expeditions for military veterans as a tool for readjustment to civilian life after returning from overseas
 - vii. Letter to Interior Secretary Sally Jewell from Ann McNally, Northern Lakes Canoe Base dated September 8, 2015
 - viii. Press Release dated July 28, 2017 from Public Lands Event at Northern Tier High Adventure Boy Scout Base, Ely, Minnesota
 - ix. "Leading with Integrity: The Scouting Journey of ExxonMobil CEO Rex Tillerson" (2017) – Mark Ray, *Eagles' Call*, Boy Scouts of America
 - x. "Summer Adventures" – *Northern Tier Adventure*. Boy Scouts of America

- xi. "Letter on BWCAW" to BLM Director Neil Kornze and Forest Service Chief Tom Tidwell dated April 1, 2016 from Scott Gudes, American Sportfishing Association, Alexandria, Virginia
 - xii. Map and Fact Sheet – Youth & Family Camps that Use the BWCA
 - xiii. "Interior Secretary touts BWCAW as 'special place'" (Apr. 21, 2016) – *The Timberjay*
 - xiv. "BWCAW Rules: Respect for the Wilderness; Dispatch No. 10 from the Freeman's Year in Our Nation's Most Popular Wilderness Area" (June 3, 2016) – By Amy Freeman, *Canoe & Kayak*
 - xv. "Can nature advocates save threatened Boundary Waters wilderness – again?" (July 26, 2016) – By Char Miller, *The Conversation*
 - xvi. "9 Places to Go to Enjoy the Great Outdoors" (Sept. 26, 2016) – National Geographic
 - xvii. "16 unexpected adventures you need to experience" (Nov. 4, 2016) – Expedia
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- i. International Joint Commission (IJC) letter dated January 22, 2015 to International Rainy-Lake of the Woods Watershed Board (IRLWWB), responding to October 21, 2014 IRLWWB Letter to IJC
 - ii. International Joint Commission letter dated January 22, 2015 to U.S. State Department & Canadian Ministry of Foreign Affairs & International Trade, RE: Mining Transboundary and Cumulative Effects of Mining expressing concern over possible cumulative and transboundary effects of proposed sulfide-ore copper mining and requesting a briefing from both governments on how binational cumulative effects will be determined
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 - c. US Forest Service. "Questions & Answers." December 2016
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COPPER SULFIDE MINING:

THE TRACK RECORD OF WATER QUALITY IMPACTS RESULTING FROM PIPELINE SPILLS, TAILINGS FAILURES AND WATER COLLECTION AND TREATMENT FAILURES.

A peer-reviewed study of the track record of water quality impacts from operating U.S. copper sulfide mines found severe impacts to drinking water aquifers, contamination of farmland, contamination and loss of fish and wildlife and their habitat, and risks to public health.¹ In some cases, water quality impacts were so severe that acid mine drainage at the mine site will generate water pollution in perpetuity.

Report findings:

In 2012, state and federal documents were reviewed for fourteen copper sulfide mines representing 89% of U.S. copper production in 2010 – the most recent data on copper production available from the U.S. Geological Survey. These mines provided a representative view of the types of environmental impacts resulting from the development of copper sulfide deposits, focusing on pipeline spills, tailings failures and water collection and treatment failures.

The report found that:

- **All of the mines (100%) experienced pipeline spills or other accidental releases.**

The most frequent spills were reported at the Ray Mine in Arizona, where over fifty pipeline spills occurred from 1988 to 2012. Examples of recent pipeline spills include a 2012 spill at the 186,000 gallons of sulfuric acid along two miles of Chase Creek - a tributary of the San Francisco River, and a 2009 spill of 2 million gallons of process water at the Bagdad Mine.

- **At 13 of the 14 mines (92%), water collection and treatment systems have failed to control contaminated mine seepage, resulting in significant water quality impacts.**

The development of acid mine drainage was associated with the most severe and lasting impacts. For example, the Tyrone and Chino mines – the two largest copper mines in New Mexico, will generate an estimated 2 billion gallons of acid and metals contaminated seepage

¹ Earthworks, U.S. Copper Porphyry Mines: The Track Record of Water Quality Impacts Resulting from Pipeline Spills, Tailings Failures, and Water Collection and Treatment Failures, July 2012 (Revised November 2012). Available at:

every year, requiring water treatment in perpetuity. These two mines have resulted in severe surface and groundwater contamination, and the State of New Mexico and U.S. Department of Justice have filed natural resource damage claims against the company for damages to water and wildlife resources.

The Bingham Canyon Mine, the largest open pit copper mine currently operating in the United States, will also generate water pollution in perpetuity from the mine's waste rock piles. Mine operations have resulted in a plume of contaminated groundwater extending over 70 square miles, and the State of Utah filed a natural resource damage claim against the mine in 2008 for impacts to water and wildlife resources.

➤ **Tailings spills have occurred at nine operations, and a partial failure of the tailings impoundment occurred at four out of fourteen mines (28%).**

These included a 1997 partial failure of the tailings impoundment at the Pinto Valley Mine, where the creek bed and surrounding upland were buried under material as deep as 42 feet. In 1993, heavy precipitation caused the Gila River to flood and breach the tailings impoundment at the Ray Mine, carrying pollutants 11 miles downriver. And in 1980, 2.6 million cubic yards of tailings were released at the Tyrone mine, and flowed 8 kilometers downstream.

Many of the currently operating copper sulfide mines are located in the arid southwest, where precipitation is limited, and communication between surface and groundwater resources is limited. More significant impacts could be expected at mines in wetter climates, with abundant surface water and shallow groundwater. Research shows that mines with high acid generating potential and in close proximity to surface and groundwater are at highest risk for water quality impacts.



Mine pollution at Arizona copper mine.

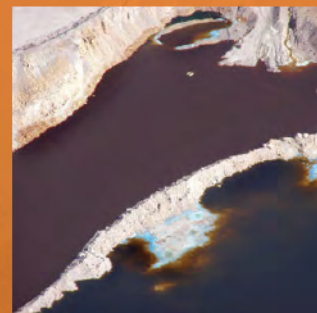


Tailings pond at copper sulfide mine.

U.S. Copper Porphyry Mines Report

THE TRACK RECORD OF WATER
QUALITY IMPACTS RESULTING FROM
PIPELINE SPILLS, TAILINGS FAILURES
AND WATER COLLECTION AND
TREATMENT FAILURES.

JULY 2012
(REVISED 11/2012)



U.S. COPPER PORPHYRY MINES:

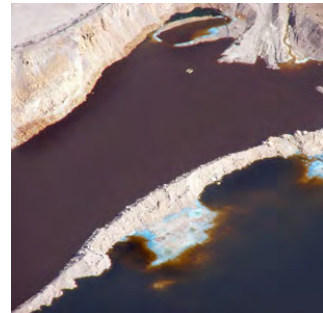
The track record of water quality impacts resulting from pipeline spills, tailings failures and water collection and treatment failures.

EARTHWORKS, July 2012

(Revised 11/2012)

By Bonnie Gestring

Reviewed by Dave Chambers Ph. D.,
Center for Science in Public Participation (CSP2)

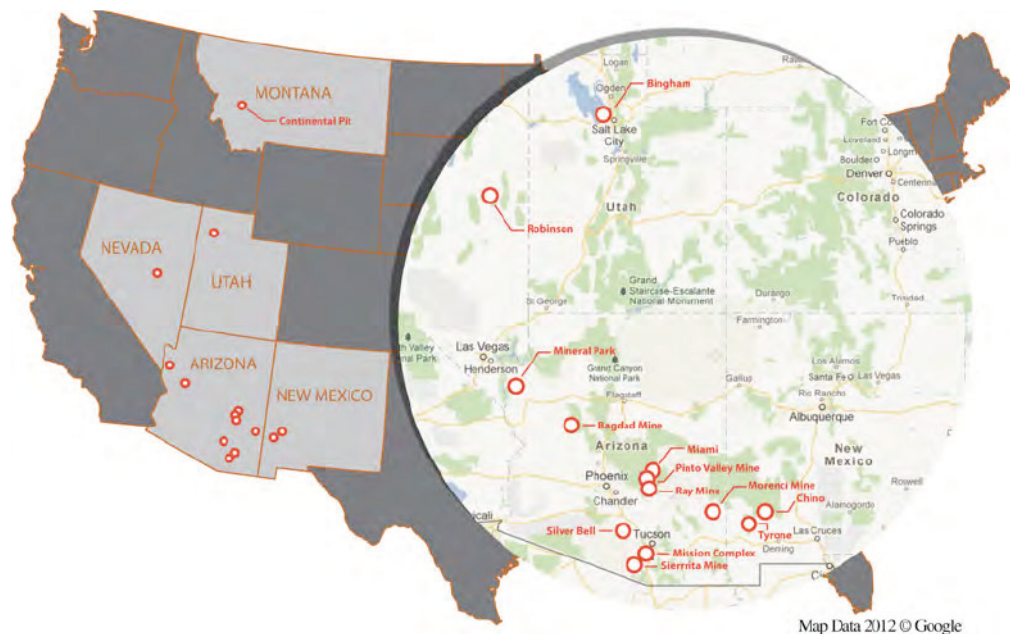


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INTRODUCTION:

The Pebble Mine is proposed for development at the headwaters of the Bristol Bay watershed in southwest Alaska, which supports the world's largest wild sockeye salmon fishery. According to current ore estimates, the Pebble Mine would be the largest copper porphyry mine in the U.S., if constructed.

Currently, the U.S. Environmental Protection Agency (EPA) is completing a watershed assessment to evaluate the potential impacts of large-scale mining on water quality and fishery resources using a mine scenario that reflects the expected characteristics of mining operations at the Pebble deposit.

The purpose of this report is to compile the record of pipeline, seepage control and tailings impoundment failures at operating copper porphyry mines in the U.S., and to document associated water quality impacts.

Copper porphyry is a form of copper deposit that is often characterized as low-grade, typically with 0.4% and 1.0% concentration of copper, and containing other minerals such as gold, molybdenum, and other trace elements in the ore body. Copper porphyry deposits are almost always mined in industrial-scale open pit operations.

Contact water drainage from porphyry deposits commonly has concentrations of aluminum, cadmium, copper, iron, manganese, lead, and zinc that exceed US drinking-water limits, which were developed to protect public health, and also commonly exceeded for cadmium, copper, lead and zinc aquatic life standards, developed to protect fish and other sensitive aquatic organisms.¹

METHODS:

We reviewed state and federal documents and a federal database for fourteen copper porphyry mines currently operating in the U.S. with respect to three failure modes: pipeline spills or other accidental releases, tailings spills or tailings impoundment failures, and failure to capture and treat mine seepage.

The 14 mines represent 87% (14 out of 16) of currently operating copper porphyry mines, and 89% of U.S. copper production in 2010 – the most recent data on copper production available from the U.S. Geological Survey. The mines were chosen based on an operating record of more than five years. These mines provide a representative view of the types of environmental impacts resulting from the development of copper porphyry deposits, focusing on pipeline spills, tailings failures, and water collection and treatment failures.

RESULTS:

Our research shows that copper porphyry mines are often associated with water pollution associated with acid mine drainage, metals leaching and/or accidental releases of toxic materials. We found that all of the mines experienced at least one failure, with most mines experiencing multiple failures:

- At 14 of the 14 mines (100%), pipeline spills or other accidental releases occurred. The most frequent spills were reported at the Ray Mine in Arizona, where over fifty pipeline spills occurred from 1988 to 2012. Examples of recent pipeline spills include a 2012 spill at the Ray Mine which washed tailings into the Gila River, and a 2008 pipeline spill at the Morenci Mine of 186,000 gallons of sulfuric acid along two miles of Chase Creek - a tributary of the San Francisco River.
- At 13 of the 14 mines (92%), water collection and treatment systems have failed to control contaminated mine seepage, resulting in significant water quality impacts. The development of acid mine drainage was associated with the most severe and lasting impacts. For example, at the Tyrone and Chino mines – the two largest copper porphyry

mines in New Mexico, seepage from tailings impoundments and waste rock piles have resulted in surface and/or groundwater pollution. The State of New Mexico and U.S. Department of Justice have filed natural resource damage claims against the company for damages to water, fish and wildlife resources.

- At 4 out of 14 mines (28%), partial tailings impoundment failures have occurred, and at 9 out of 14 mines (64%), tailings spills have occurred. These included a 1997 partial failure of the tailings impoundment at the Pinto Valley Mine, where 8.1 acres of creek bed and surrounding upland were buried under material as deep as 42 feet. In 1993, heavy precipitation caused the Gila River to flood and breach the tailings impoundment at the Ray Mine, carrying pollutants 11 miles downriver. And in 1980, 2.6 million cubic yards of tailings were released at the Tyrone mine, and flowed 8 kilometers downstream.

CONCLUSION:

Our research shows that water quality impacts to surface and/or groundwater are common at currently operating copper porphyry mines in U.S., resulting from three failure modes (pipeline spills or other accidental releases, failure to capture and treat mine seepage, and tailings spills or impoundment failures).

These failures resulted in a variety of environmental impacts, such as contamination of drinking water aquifers, contamination and loss of fish and wildlife and their habitat, and risks to public health. In some cases, water quality impacts are so severe that acid mine drainage will generate water pollution in perpetuity.

This research demonstrates that the three failure modes identified in the Bristol Bay watershed assessment with respect to risks to water quality are reasonable and well-supported by the track record of operating copper porphyry mines in the U.S.

Many of the currently operating copper porphyry mines are located in the arid southwest, where precipitation is limited, and communication between surface and groundwater resources is limited. While beyond the scope of the analysis in this report, more significant impacts could be expected at mines in wetter climates, with abundant surface water and shallow groundwater, such as is the case in the Bristol Bay region. Research shows that mines with high acid generating potential and in close proximity to surface and groundwater are at highest risk for water quality impacts.²

Table 1**2010 copper production amounts for mines reviewed in this report.**

Mine	Location	Company	2010 Copper production (Metric Tons)
Bingham Canyon	UT	Kennecott/Rio Tinto	250,000 ³
Morenci	AZ	Freeport	233,146 ⁴
Ray	AZ	ASARCO	105,051 ⁵
Bagdad	AZ	Freeport	92,079 ⁶
Mission	AZ	ASARCO	83,415 ⁷
Sierrita	AZ	Freeport	66,678 ⁸
Robinson	NV	Quadra	49,400 ⁹
Tyrone	NM	Freeport	37,194 ¹⁰
Silver Bell	AZ	ASARCO	21,000 ¹¹
Chino	NM	Freeport	15,400 ¹²
Mineral Park	AZ	Mercator	14,605 ¹³
Miami	AZ	Freeport	8,100 ¹⁴
Pinto Valley	AZ	BHP	6,000 ¹⁵
Continental Pit	MT	Montana Resources	Not available
Total production of 13 mines			982,068
Total U.S. production			1,100,000
Percent of total production			89%

Table 2

Synopsis of pipeline spills, tailings spills and impoundment failures, and water capture and treatment failures for 14 copper porphyry mines (1986-2012).

Mine	Number of reported pipeline spills and other accidental releases*	Water collection and treatment failures	Tailings dam failures	Affected surface and/or ground water
Morenci	21	Yes		San Francisco River, Gila River, Chase Creek, groundwater aquifer
Bingham Canyon	28	Yes		72 square mile plume of contaminated groundwater; fish and wildlife habitat in the Great Salt lake ecosystem
Ray	54	Yes	Partial	Mineral Creek, Gila River, groundwater aquifer
Chino	10	Yes		Hanover/Whitewater Creek, contaminated groundwater will require water treatment in perpetuity
Bagdad	7	Yes	Partial	Boulder Creek, Burro Creek, Butte Creek, Bridle Creek
Sierrita	18	Yes		Demetrie Wash and its tributaries; groundwater aquifer including drinking water wells in Green Valley
Pinto Valley	3	Yes	Partial	Pinto Creek
Mission	3	Yes	Partial	Tributaries of the Santa Cruz River, groundwater aquifer
Robinson	8	Unknown		2.3 miles of downstream drainage bed
Tyrone	7	Yes	Partial	Mangas Creek, groundwater contamination will require water treatment in perpetuity
Mineral Park	3	Yes		Groundwater aquifer and surface water
Miami	8	Yes		Pinal Creek alluvial aquifer
Silver Bell	3	Yes		Cocio Wash
Continental Pit	2	Yes		Groundwater aquifer

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

CASE STUDIES:

MORENCI MINE, AZ (Freeport McMoRan) The Morenci Mining District is located in southeastern Arizona, near the towns of Clifton and Morenci. It is located near the Gila River, the San Francisco River and Eagle Creek.	
Reports of pipeline failures and other accidental releases*	2008: Report of pipeline spill releasing 186,000 gallons of sulfuric acid and heavy metals into a tributary (Chase Creek) of the San Francisco River, resulting in a \$150,000 settlement with the State of Arizona.¹⁶ The highly acidic material traveled downstream more than 2 miles. The pollutants in the discharge exceeded Arizona surface water quality standards for copper, zinc and pH in Lower Chase Creek. 2007: Report of release of 1,200,000 gallons of pregnant leach solution released due to power failure.¹⁷ 2006: Report of release of 3,000 pounds of sulfuric acid from pipeline break.¹⁸ 2006: Report of 1,127 pounds of material from PLS pipeline.¹⁹ 2006: Report of release of rich electrolyte (acid content 1,057 pounds) from an underground process pipeline.²⁰ 2004: Report of release of 8,920 pounds of sulfuric acid and water from process pipeline due to failure of valve.²¹ 2001: Report of release of 6,350 pounds of sulfuric acid released from pipeline.²² 2000: Report of release of 72,000 gallons of sulfuric acid released from pipeline.²³ 1998: Report of release of 66,200 pounds of sulfuric acid released from pipeline.²⁴ 1996: Report of release of unknown amount of pregnant leach solution spilled from pipeline, affecting Chase Creek, leading to San Francisco River.²⁵ At the time of report, 20 gpm were being released. 1996: Report of release of 160,000 gallons of process solution spilled due to pipeline weld failure.²⁶ 1996: Report of release of 50,000 pounds of sulfuric acid spilled due to backhoe hitting pipeline.²⁷ 1996: Report of 12,435 pounds of sulfuric acid released from pipeline.²⁸ 1995: Report of 2,980 pounds of sulfuric acid released from pipeline.²⁹ 1994: Report of 203,400 gallons of raffinate released due to ruptured pipe.³⁰ 1994: Report of 5,400 pounds of sulfuric acid released due to fractured weld in pipeline.³¹ 1993: Report of unknown amount of copper sulfate released into San Francisco River due to storm event.³² 1993: Report of 180,000 gallons of pregnant leach solution spilled due to plugged drain line, affected 1 acre.³³ 1992: Report of 2,500 gallons of electrolyte released.³⁴ 1992: Report of 15,000 pounds of copper sulfate spilled due to valve failure.³⁵ 1992: Report of 7,500 gallons of electrolyte spilled due to failure of pipeline weld.³⁶
Water collection and treatment failures	In 2012, the U.S. Dept of Justice and the State of Arizona released a consent decree which found that, "mine tailings exposed to air and precipitation released hazardous substances on the surface of the tailings or that can percolate through the tailings to groundwater." The consent decree found that, "releases of hazardous substances at or from the Morenci mine site have occurred and allege that such releases have caused injuries to natural

	resources at and in the vicinity of the site including surface water, sediments, soils, terrestrial habitats and terrestrial receptors.”³⁷ A financial settlement followed an investigation of natural resource injuries related to the release of hazardous substances into the environment from acid mine drainage and process solution, among other sources. The investigation found that the main ore minerals are sulfide minerals, which have resulted in the development of acid mine drainage. According to the report, “Surface water has been, and most likely continues to be, exposed to hazardous substances released from the Morenci Mine through a variety of pathways.”³⁸ Concentrations of hazardous substances measured in groundwater at the Morenci Mine and measured in the San Francisco and Gila Rivers downstream of the mine provide further indications that hazardous substances present in the source materials at the Morenci Mine have been released to the environment. The report found that “Concentrations of total and dissolved zinc have exceeded 1,000 ug/l in the Gila River and concentration of dissolved copper have exceeded 100 ug/l in the San Francisco River.”³⁹ Contaminated groundwater is also released to surface water via seeps and springs.⁴⁰
Tailings spills and impoundment failures	No impoundment failures.
Impacts to water, fish and wildlife	In 2012, the US Department of Justice and Department of Interior have jointly announced that Freeport McMoRan has agreed to pay \$6.8 million to settle federal and state natural resource damages related to the Morenci Mine. According to the complaint, the hazardous substance release, which included sulfuric acid and metals, injured, destroyed or led to the loss of “surface waters, terrestrial habitat and wildlife, and migratory birds.”⁴¹ As described above, metals contamination occurred in the San Francisco and Gila Rivers downstream of the mine, and to groundwater supplies.

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

BINGHAM CANYON MINE and SMELTER, UT (Kennecott)
The Bingham Canyon Mine is the deepest open pit mine in the world, located southwest of Salt Lake City, Utah.

Reports of pipeline failures and other accidental releases*

2011: Report of malfunction of equipment that allowed the release of approximately 145,424 gallons of copper tailings.⁴²

2011: Report of pipeline overflow onto soil with estimated 100,000 – 290,000 gallons of copper tailings material released from pipeline.⁴³

2011: Report of tailings slurry released from tailings slurry hot box. 160,000 gallons of tailings released.⁴⁴

2010: Report of a release of process water due to broken pipeline.

2010: Report of a discharge of sulfuric acid from a pipeline in the precious metal plant released between 4,000-5,000 gallons.⁴⁵

2007: Report of a release of 35,000 gallons of hydromet tails containing arsenic due to pipeline break.⁴⁶

2007: Report of 1,240,000 gallons of process water containing arsenic from pipeline break due to cold temperatures.⁴⁷

2006: Report of 270,000 gallons of process water released because of pump failure, which resulted in overflow of containment area.⁴⁸

2006: Report of 660,000 gallons of process water containing arsenic released due to cracked pipe.⁴⁹

2006: Report of 1,000,000 gallons of process water released from the Magna Reservoir due to a failed level indicator.⁵⁰

2004: Report of 4,000,000 gallons of process water with arsenic from pipeline.⁵¹

2004: Report of 2,000,000 gallons of process water with arsenic from broken process water line.⁵²

2004: Report of 202,000 gallons of process water released due to pipeline failure.⁵³

2003: Report of 70,000 gallons of process water with arsenic released due to pipeline failure.⁵⁴

2003: Report of 70 tons of copper concentrate released from pipeline.⁵⁵

2003: Release of copper concentrate, containing 340 pounds of arsenic, 20,000 pounds of copper, and 200 pounds of lead.⁵⁶

2003: Copper concentrate pipeline ruptured, releasing 240,000 tons of copper, 428 tons of arsenic, 253 tons of lead.⁵⁷

2002: Report of 5,800 gallons of process water from slag pot cooling area due to plugged drain line.⁵⁸

2001: Report of tailings pipeline failure, releasing 4 pounds of arsenic, 14 pounds of chromium and 1 pound of lead.⁵⁹

2000: Report of 110 tons of ore slurry released due to a leak in ore line.⁶⁰

2000: Report of 18,000 tons of sulfuric acid released from pipe due to flange failure.⁶¹

1999: The process water pipeline sprung a series of leaks in 1989 and 1999. It has been estimated that 100 million gallons of process water with high arsenic levels spilled before the leak was discovered.⁶²

1998: Report of copper sulfate released into a canal.

1998: Report of clogged piping system causing pipe to back up and overflow releasing acid

	rock drainage into water. 1997: Report of settling pond overflow due to clogged outlet valve. Release of copper sulfate into water. 1997: Report of pipeline rupture releasing process water (pH 2.5-4.0) into water. 1993: Report of 45,000 gallons of wastewater spilled due to a rupture of the transfer line.⁶³ 1991: Report of 30,000 gallons of industrial wastewater spilled at the wastewater treatment plant due to line break.⁶⁴
Water collection & treatment failure	2011: Noncompliance in April-June 2011 for discharges of copper, zinc and total suspended solids at copper smelter.⁶⁵ Wastewater from the mine has escaped the site's collection system, contaminating groundwater with acid, metals and sulfates. The groundwater plume extends towards the nearby Jordan River and covers more than 72 square miles – rendering water for thousands of Salt Lake City residents undrinkable.⁶⁶ There have been multiple tailings spills.⁶⁷ Drainage from the waste rock piles will require water treatment in perpetuity to prevent additional groundwater pollution.⁶⁸ In February 2008, the United States Fish and Wildlife Service took legal action against Kennecott for the release of hazardous substances from the mine's facilities, including selenium, copper, arsenic, lead, zinc and cadmium.⁶⁹ Groundwater contaminated by mine operations has been released from the mine site through artesian springs into areas that serve as fish and wildlife habitats. According to the federal biologists, the release of these hazardous pollutants has harmed natural resources, including migratory birds and their support ecosystems, which includes wetlands, marshes, freshwater wildlife habitats, playas and riparian areas and freshwater ponds.⁷⁰
Impacts to water, fish and wildlife.	In February 2008, the United States Fish and Wildlife Service took legal action against Kennecott for the release of hazardous substances from the mine's facilities, including selenium, copper, arsenic, lead, zinc and cadmium.⁷¹ Groundwater contaminated by mine operations has been released from the mine site through artesian springs into areas that serve as fish and wildlife habitats. According to the federal biologists, the release of these hazardous pollutants has harmed natural resources, including migratory birds and their support ecosystems, which includes wetlands, marshes, freshwater wildlife habitats, playas and riparian areas and freshwater ponds.

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

RAY MINE and HAYDEN SMELTER, AZ (ASARCO)

The Ray Mine is a copper mining facility of approximately 6,100 acres near Kelvin, Arizona which discharges into Mineral Creek, a tributary of the Gila River, and the Hayden Facility is a smelting facility located in Hayden Arizona along the Gila River.

Reports of pipeline failures and other accidental releases*

2012: Potable water line ruptured, which washed tailings into the Gila River.⁷²

2007: A leak from a coupling in a tailings pipeline spilled tailings onto the banks and into the Gila River. A \$20,000 civil penalty was paid.⁷³ According to the report, the pipeline had been in use since the construction of "d" tailings impoundment (about 1985), was in good condition, and was visually inspected on a frequent basis. A support structure failed on Feb. 4, 2007, resulting in an angular deflection at one of the couplings, resulting in the tailings leak.⁷⁴

2007: Report of 1,000 pounds of sulfuric acid spilled from pipeline.⁷⁵

2006: Report of 600 gallons of sulfuric acid spilled due to piping failure inside of mine.⁷⁶

2000: Report of 80.95 pounds of copper sulfate released from basin/dam into Mineral Creek.⁷⁷

2000: Report of 200 gallons of copper sulfate spilled from pipe.⁷⁸

1999: Report of 33,000 gallons of tailings water released from pipeline.⁷⁹

Between August 1988 and November 1997, 47 separate releases of hazardous substances into Mineral Creek from the Ray Mine were reported.⁸⁰

According to a 2012 ecological risk assessment prepared by the State of Arizona, "A large portion of these releases were uncontained and eventually entered Mineral Creek and the Gila River. Hazardous chemicals released included copper sulfate, copper tailings and leachate."⁸¹ In addition, the report found that multiple groundwater wells downgradient of the Ray Mine were found to be highly contaminated by a common leachate solution which was attributed to releases to shallow groundwater along Mineral Creek, and it concluded that "it is likely that the hazardous substances present in shallow groundwater will represent an ongoing source of chronic contamination to Mineral Creek (Lipton 2009)."⁸²

According to a report by the U.S. EPA, at least 19 spills of hazardous materials were reported at the Ray Mine from August 1990 through November 1993.⁸³ The majority of spills were from dams, pipelines, and ponds. The discharges typically resulted from either accidental discharges associated with heavy rain or from chronic seepage from leaching facilities into the ground water, which then entered the creek. The report found that, "surface water quality has been significantly affected." A total of 41 violations of total copper, dissolved copper, and beryllium numeric surface water quality standards were documented by the Arizona Department of Environmental Quality (ADEQ), EPA, and ASARCO in Mineral Creek below the Ray Mine.⁸⁴

According to the report, "Arizona's Department of Game and Fish believes that the discharges from the Ray Unit have negatively affected both the water quality and the aquatic life of Mineral Creek. The Department conducted a biosurvey of Mineral Creek in July 1993. In a report dated September 30, 1993, the Department found that although the numbers and diversity of aquatic insects and fish were high above the Ray Unit, an almost complete absence of aquatic life at sampling stations was observed directly downstream of the mine."⁸⁵

Water collection and

According to an EPA report, "The mine's routine operations are chronically affecting the quality of both surface and ground waters in the mine's vicinity."⁸⁶ According to the report, the Arizona Dept. of Environmental Quality reported in 1996 that approximately

treatment failures	one-half mile of the Mineral Creek streambed below the Ray Mine was visibly affected by mine activities. The streambed was coated with a blue-green layer of copper oxides.⁸⁷ In April 1995, EPA reported that six ground water wells situated downgradient of the electrowinning plant and the electrowinning dam were continuously pumping PLS.⁸⁸ Multiple groundwater wells were found to be highly contaminated by a common leachate solution which was attributed to releases by ASARCO into shallow groundwater along Mineral Creek. It concluded that it is likely that the hazardous substance present in shallow groundwater will represent an ongoing source of chronic contamination to Mineral Creek (Lipton 2009).⁸⁹
Tailings spills and impoundment failures	2012: Seepage from the tailings impoundment was released into two catch basins and into a tributary of the Gila River.⁹⁰ At the time of the report, seepage into the tributary was estimated at 75 gpm. The incident occurred as a result of operator error during the initiation of a new upstream construction method at its Elder Gulch Tailings Impoundment in 2011.⁹¹ A delay in the completion of the tailings distribution line resulted in the uneven distribution of the tailings, which in turn caused the ponded water to migrate, and eventually be released from the impoundment into drainages. The seep was discovered on January 30, 2012, and seep flow from the embankment was observed to have stopped on February 7, 2012. 2011: A report of 6,000-8,000 tons of copper ore tailings released from one of the tailings pond due to a breach in the dike.⁹² The company failed to operate and maintain all listed permitted facilities in its Aquifer Protect Permit No. P-100507 to prevent the unauthorized discharge of copper ore tailings.⁹³ In 1993, heavy precipitation caused the Gila River to flood, and breach the AB-BC tailings impoundment containment dike.⁹⁴ According to a report by the U.S. EPA, "Continued flooding over the next several days resulted in a total of 13 separate breaches of the dike, three of which eroded through the dike and into the toe of the tailings pile. The total discharge was approximately 292,000 tons of tailings, which was about 216,000 cubic yards of material."⁹⁵ It also found that sampling of the river showed that elevated concentrations of pollutants occurred at least 11 miles downstream of the spill. The tailings formed bank and bottom deposits in the river, impairing both recreational uses and the quality of habitat for plants and animals.⁹⁶
Impacts to water, fish and wildlife	In April 2009, the Department of the Interior and the State of Arizona, acting as natural resource trustees (Trustees) received a monetary settlement and three parcels of land from ASARCO, L.L.C. through the Natural Resource Damage Assessment and Restoration (NRDAR) program to account for injuries to trust resources incurred through multiple releases of hazardous substances by ASARCO L.L.C. into Mineral Creek and the Gila River in Pinal County, Arizona.⁹⁷ According to a 2012 ecological risk assessment by the State of Arizona, "The site of injury stretches from the Ray Mine and the Hayden Facility, to the Gila River from the Ashurst-Hayden Diversion Dam, upstream past the confluence of the San Pedro and Gila Rivers, and for a distance of 5 miles up each of those rivers beyond the confluence and to Mineral Creek from its confluence with the Gila River upstream to a point one mile above the Big Box Canyon Dam." The most substantial injuries occurred in the reach of Mineral Creek that extends from the tunnel outlet to the Gila River. The report finds that, "Dissolved copper concentrations in the surface water of this reach have been recorded up to 130 times surface water quality standards that will sustain aquatic life, and sediment copper concentrations have been recorded to exceed up to 22 times the level beyond which injury is inflicted on sediment-dwelling organisms (MacDonald et al. 2000)."⁹⁸ These concentrations of copper caused a complete loss of aquatic life in this reach. Overall, the report found that, "ecosystem services lost in the 117 acres that include Mineral Creek and its associated riparian habitat were estimated to be 100% from 1981-

	2005, and up to 50% from 2005 to the present (Lipton 2009). Hazardous releases also affected the aquatic and riparian portions of the Gila River near the Ray Mine/Hayden Smelter Complex, including approximately 2,930 acres upstream of Mineral Creek to the confluence with the San Pedro River, and approximately 1,620 acres downstream of Mineral Creek to the Ashurst-Hayden Dam. The most substantial loss of ecosystem services in these areas occurred during the three years following the release of 300,000 tons of tailings in 1993, when ecosystem service losses were estimated at 10-25% (Lipton 2009). ⁹⁹
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*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

CHINO MINE, NM (Freeport McMoRan) The Chino Mine is located approximately 12 miles southeast of Silver City, New Mexico. The site is east of the Continental divide and drains into ephemeral drainages in the Mimbres watershed.	
Reports of pipeline failures and other accidental releases*	2007: A spill involving one million gallons of acidic mine waters overflowed a containment sump into a storm water diversion channel and traveled more than two and a half miles down a surface water tributary near the mine. The spill resulted in groundwater contamination and a settlement of \$276,000 was reached with the State of New Mexico.¹⁰⁰ Multiple other tailings spills have occurred, which are listed below:¹⁰¹ 2000: Report of 480,000 gallons of tailings slurry discharged, with 93,000 gallons entering Whitewater creek. 1999: Report of 3.25 million gallons of tailings spilled into Whitewater Creek. 1997: Report of 100,000 gallons of tailings spilled into Whitewater Creek. 1996: Report of 152,000 gallons of liquid tailings spilled into Whitewater Creek. 1993: Report of 208 tons and 91,500 gallons of tailings accidentally released to Whitewater Creek in six separate incidents resulting from the rupture of degraded pipes. 1992: Report of 120,000 gallons of tailings spilled into a basin. 1991: Report of 3,200 gallons of tailings released into Whitewater Creek when a tailings pipeline ruptured. 1988: Heavy rains led to the release of 180 million gallons of acidic wastewater into Whitewater Creek over a 35-day period. Analysis of the wastewater indicated that it had 30 times the allowed levels of the hazardous substance cadmium, as well as more than 30 times the allowed levels of sulfates.¹⁰² Enlargement of the precipitation plant reservoir was completed in 1985 to prevent overflows of leachate solution into Whitewater Creek. Above average precipitation however caused the new reservoir to overflow and discharge waters to Whitewater Creek on October 9 and 10, 1985; May 6, 1986 and October 6, 1986.¹⁰³
Water collection and treatment failures	In 2011, the U.S. Department of Justice and State of New Mexico issued a consent decree for damages to natural resources from hazardous substances from the Chino, Tyrone and Cobre mines.¹⁰⁴ The settlement followed an investigation of natural resource injuries related to the release of hazardous substances into the environment from acid mine drainage and process solution, among other sources. It found that, "surface water and associated sediments are exposed to hazardous substances released from the Chino Mine through a variety of pathways, including leaks and spills of process water, tailings spills; runoff, and infiltration or percolation from tailings and waste stockpiles."¹⁰⁵ Groundwater contamination from tailings pond #7, which became active in 1988, has occurred to the east, west and south of impoundment. It also found that hazardous substances have been released into groundwater at the Chino mine from multiple source areas.¹⁰⁶ Concentrations of hazardous substances in groundwater in exceedance of water quality standards confirm release to groundwater throughout the Chino Mine. Groundwater flow modeling for the North Mine area indicates that contaminated groundwater in four of these areas is not captured by dewatering in the main pit. In the South Mine area, groundwater has exceeded standards for manganese and cadmium at Middle Whitewater Creek, Hurley and Lake One, and has exceeded standards for copper at Lake One.¹⁰⁷

	A 2012 assessment of groundwater impacts concluded that contaminated seepage from the mine will require water treatment in perpetuity. ¹⁰⁸
Tailings spills and impoundment failures	Tailings spills (see above).
Impacts to water, fish and wildlife	The 2003 ecological risk assessment reported elevated concentrations of the hazardous substances copper and zinc in surface water from five different drainages at the Chino Mine, including Hanover/Whitewater Creek, Bayard Canyon, Bolton Draw, the unnamed drainage between Bolton Draw and Lampbright Draw and Lampbright Draw.¹⁰⁹ The areal extent of injured alluvial and regional groundwater at the Chino Mine is 13,935 acres.¹¹⁰ According to the closure plan for the Chino Mine, contaminated groundwater will require water treatment in perpetuity.¹¹¹

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

BAGDAD MINE, AZ (Freeport McMoRan) The Bagdad Mine is an open pit copper and molybdenum complex 100 miles northwest of Phoenix, Arizona.	
Reports of pipeline failures and other accidental releases*	2009: Report of a broken pipeline causing a release of 2,378,500 gallons of sulfuric acid. ¹¹² 2007: Report of 22,500 gallons of raffinate solution containing sulfuric acid spilled from a pond. ¹¹³ 2004: Report of 7,484 pounds of sulfuric acid released due to malfunction of pipe. ¹¹⁴ 2004: Report of 354 pounds of sulfuric acid released due to crack in pipe. ¹¹⁵ 1999: Report of 12,000 gallons of process water with residual chlorine spilled into Bridle Creek. ¹¹⁶ 1997: Report of 1,500 pounds of sulfuric acid due to pipeline failure. ¹¹⁷ 1997: Report of 7,200 pounds of sulfuric acid overflowed from pond due to drain blockage. ¹¹⁸
Water collection and treatment failures	In 1996, the EPA and the state of Arizona announced that Cyprus Bagdad Copper Corp., a subsidiary of Cyprus Mineral Corp., paid penalties totaling \$760,000 for discharging contaminated water from the Bagdad Copper Mine.¹¹⁹ The discharges involved various facilities including tailings ponds, leach dumps, and a sewage treatment plant, but by far the major discharges came from the Copper Creek Leaching Basin, in which acidic, copper-tainted underground seepage entered Boulder Creek.¹²⁰ According to an EPA report, seepage of pregnant leach solution from the Copper Creek Leaching System was discovered in a receiving pool in Boulder Creek in 1991.¹²¹ Studies indicated that instead of being contained by the Copper Creek Flood Basin, the heavily contaminated solution seeped under the dam. The concentration of total copper in samples collected in the pool in Boulder Creek were as high as 76.4 mg/l. On March 29, 1993, U.S. EPA issued a Finding of Violation and Order against Cyprus.¹²² According to a 2006 study that compared the water quality predictions made during mine permitting with water quality impacts during operations, although no water quality impacts were predicted during the permitting process, the following water quality violations occurred: Water quality monitoring (1998-2002) in Boulder Creek, found water quality exceedances for arsenic, lead, mercury, and selenium. In Burro Creek, there were water quality exceedances for copper and mercury. In Butte Creek, there were water quality exceedances for mercury and selenium.¹²³
Tailings impoundment spills and/or failures	
Impacts to water, fish and wildlife	Copper and low pH releases to ground and surface waters, hazards to aquatic life from solution releases beneath and over containment system dam. Water quality impacts to Boulder Creek, Burro Creek and Butte Creek.

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

SIERRITA MINE, AZ (Freeport McMoRan) The Sierrita Mine is an open pit copper and molybdenum mining complex 20 miles southwest of Tucson, Arizona.	
Reports of pipeline failures and other accidental releases*	2011: Report of 849 gallons of sulfuric acid spills from a pipeline leak.¹²⁴ 2008: Report of 1,100 gallons of sodium hypochlorite spilled due to loose pipe.¹²⁵ 2005: Report of 1,000 pounds of sulfuric acid from a broken pipeline.¹²⁶ 2005: Report of 8,058 pounds of sulfuric acid released from a broken pipeline.¹²⁷ 2002: Report of 39,375 pounds of sulfuric acid spilled from a pipeline due to a separated flange.¹²⁸ 2001: Report of 1,209 pounds of sulfuric acid spilled from pipeline.¹²⁹ 2000: Report of 5,350 gallons of leach solution spilled from pipe.¹³⁰ 1998: Report of 160,000 gallons of mill tailings spilled into water due to overflow resulting from power failure.¹³¹ 1998: Report of 40,000 gallons leach solution spilled from pipeline.¹³² 1998: Report of 120,000 gallons of leach solution spilled from pipeline.¹³³ 1997: Report of 2,798 pounds of sulfuric acid spilled due to pipeline rupture.¹³⁴ 1997: Report of release of 8,000 pounds of sulfuric acid due to pipe joint failure.¹³⁵ 1996: Report of release of 3,000 gallons of sulfuric acid due to pipeline failure.¹³⁶ 1994: Report of another pipeline break allowed a discharge into Demetrie Wash of approximately 120,000 gallons of reclaim water.¹³⁷ 1994: Report of approximately 5,000 gallons of reclaim water were released as a result of a pipeline break.¹³⁸ 1993: Report of a leak in a pipeline transporting process water discharged approximately 200,000 gallons of a mixture of process wastewater and storm water run-off to an unnamed tributary of Demetrie Wash.¹³⁹ 1993: Report of Cyprus Sierrita discharging approximately 2,700,000 gallons into the same wash as a result of another pipeline break.¹⁴⁰ 1993: Report of approximately 450,000 gallons released to the wash in October 1993 by a broken pipeline.¹⁴¹
Water collection and treatment failures	From the summer of 1992 until December 1994, Sierrita discharged contaminated process water and storm water run-off to Demetrie Wash and its tributaries from various overflows, seepages, and pipeline leaks and breaks.¹⁴² In 1996, the U.S. Department of Justice issued a civil claim against Cyprus Sierrita on behalf of the State of Arizona and the U.S. pursuant to the Clean Water Act.¹⁴³ Cyprus Sierrita entered into a Consent Decree to pay a penalty of \$88,000 for numerous violations. According to a 2011 report, seepage from an unlined tailings pond at the Sierrita mine has sent a plume of contaminated groundwater toward the city of Green Valley, causing drinking water wells to record high levels of sulfates.¹⁴⁴ In 2006, the company signed a mitigation order on consent with the State of Arizona to address sulfate in drinking water. It requires the company to develop a mitigation plan to be submitted in 2009.
Impacts to	Ground water and surface water contamination have occurred from pipeline leaks and breaks, overflows, and underground seepage from process wastewater, wastewater, and

water, fish and wildlife	storm water surface impoundments. Drinking water wells have been affected.
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*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

PINTO VALLEY MINE, AZ (BHP Billiton) The Pinto Valley Mine is an open pit copper and gold mine located about 126 km east of Phoenix, AZ. Formerly owned by Magma Copper Company.	
Reports of pipeline failures and other accidental releases	2010: Report of a storm event, which caused 5,362 tons of tailings to spill onto soil and Pinto Creek, including 214 pounds of arsenic and 11 pounds of lead.¹⁴⁵ 500 cubic yards were released into water. Pinto Creek is a tributary to Roosevelt Lake. 2010: Report of an unknown amount of mine tailings released onto land, with a potential release to water, due to heavy rains.¹⁴⁶ 2007: A release of impounded storm and seepage water occurred due to a flange separation in a tailings line. The unexpected release washed out a section of the secondary containment, which allowed it to escape. An estimated 45,000 gallons of water (stormwater and tailings seepage) reported to an unnamed tributary to Pinto Creek.¹⁴⁷ 2001: Report of 1,725 pounds of sulfuric acid released due to pipeline break.¹⁴⁸
Water collection and treatment failures	According to a 2001 EPA report, a portion of Pinto Creek from its headwaters to Spring Creek was first listed as water quality limited in 1992 based on elevated copper concentrations and pH values that were related to discharges from the Pinto Valley and another mine. The remaining portions of the stream were added to the 303(d) list in 1994.¹⁴⁹ The report further states that, "Since 1989, extreme storm events caused releases of copper bearing sediments and liquids to Pinto Creek from Pinto Valley operations. These releases resulted from partial tailings dam failures, pipeline breaks, seepage flows, conveyance blockages, and storm water overflows. Recent significant release events occurred in August 1989, July 1990, January 1991, August to September 1991, January to February 1993, and October 1997. In each of these events, materials were released in quantities sufficient to impact Pinto Creek or its tributaries."¹⁵⁰ Based on EPA's review of discharge monitoring reports between January 1990 and September 1991, Magma (now Pinto Valley) reportedly discharged effluent to Pinto Creek or its tributaries in excess of allowable effluent limitations on numerous occasions, and/or did not collect and analyze samples, in violation of permit conditions.¹⁵¹ According to the report, during the first episode, approximately 3,000 gallons of effluent containing total suspended solids and copper of unknown concentrations was discharged from the ditch. A similar discharge of 24,000 gallons occurred on September 5, 1991. An estimated 39,000 gallons of effluent in exceedance of Arizona Surface Water Quality Standards and Aquifer Water Quality Standards for copper, zinc, and lead were discharged from the ditch on September 23, 1991.¹⁵²
Tailings spills or failures	In 1997, a partial tailings failure deposited an estimated 276,000 cubic yards of tailings in Pinto Creek.¹⁵³ It buried 8.1 acres of creek bed and surrounding upland with material as deep as 42 feet.¹⁵⁴ Another incident occurred in 1993, when heavy rainfall overwhelmed the mine's water management capabilities. During the rainfall event, a reservoir overflowed the tailings pile, tore out a levee, and carried tailings to Pinto Creek.¹⁵⁵ In addition, a retention pond that held storm water and mineral wastes discharged material into the creek after its dam was breached. According to an EPA report of the incident, "Critical water containment structures in place at the mine in 1992 were reportedly designed to hold a 100-year, 24-hour storm event. Nonetheless, the mine discharged hundreds of tons of tailings and millions of gallons of contaminated water into Pinto Creek."¹⁵⁶ Water quality sampling during January and February 1993 indicated 286 exceedances of daily and monthly water quality parameters. Fish surveys collected before and after the discharges showed a

	marked decline in populations of the desert sucker (<i>Pantosteus clarki</i>) following the discharges. Although they were abundant in 1992, a summer survey in 1993 found only one adult in Pinto Creek.¹⁵⁷ In January 1991, the face of Tailings Dam No. 3 failed, releasing 150 - 250 tons of tailings into Pinto Creek, and two million gallons of water.¹⁵⁸ In March 1991, another large quantity of tailings was released from the same pile.¹⁵⁹ This release occurred from an over-saturation of the tailings face benches due to heavy precipitation, and an estimated 3.4 million gallons of water also were discharged.
Impacts to water, fish and wildlife	Extensive impacts to surface water quality and fish habitat in Pinto Creek resulting from tailings spills, and other mine related impacts.

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

MISSION COMPLEX MINE, AZ (ASARCO) The Mission Mine complex is an open pit copper mine and underground copper mine located near Sahuarita, Arizona (18 miles south of Tucson). The Mine covers approximately 29.7 square miles, and a portion of the mine occupies tribal lands.	
Reports of pipeline failures and other accidental releases*	2011: Report of a backup of a tailing line resulting in release of tailings into a dry wash.¹⁶⁰ 2002: A violation involving the discharge of primarily copper laden stormwater runoff and process water discharge to ephemeral tributaries of the Santa Cruz river near Tucson in violation of the facilities Multi Sector General Permit Case # 09-2002-0064. 2001: Report of a 36-inch distribution tailings line releasing 200 tons of tailings into a dry stream channel.¹⁶¹
Water collection and treatment failures	According to EPA fact sheet released in 2008, discharges from mine (outfall 001A) contain significant levels of copper and lead, and TSS, which have been out of compliance since October, 2003.¹⁶² Outfalls from the Mission complex discharge to ephemeral streams that are tributaries to the Santa Cruz River. Three large tailings ponds and several mine dumps are located on land leased from the Indian landowners approximately 1 mile south of the Arroyos project area. According to a report by the Bureau of Reclamation, leachate from these tailings has contributed to elevated levels of sulfate, TDS, and hardness in the aquifer below and adjacent to the ponds.¹⁶³
Tailings spills or impoundment failures	The Bureau of Reclamation Report also states that, "Surface drainage from a break in a tailings pond dike in 1990 released large volumes of material into wash complexes that drain toward the SCR."¹⁶⁴
Impacts to water, fish and wildlife	Ground and surface water pollution.

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

ROBINSON MINE, NV (Robinson Nevada Mining Co.) Formerly owned by BHP Copper, Magma Nevada Mining Company The Robinson Mine is an open pit copper and gold mine located in eastern Nevada approximately 11 km west of Ely, Nevada.	
Reports of pipeline failures and other accidental releases*	1996: The mine experienced eight reported spills during 1996. Most of these spills involved tailings solution and reclaim water releases due to equipment failures. The five spills resulting in releases of copper flotation tailings had spill volumes ranging from 1,500 gallons to 66,000 gallons. Four of these spills resulted in contamination of relatively small areas of soil. The largest spill resulted in contamination of a downstream drainage bed for 2.3 miles with an average flow path width of 3 ft. Two spills resulted in a combined release of 76,000 gallons of reclaim water. ¹⁶⁵
Water collection and treatment failure	In 2010, the State of Nevada issued a Finding of Alleged Violation and Order for the failure to comply with permit and regulatory requirements regarding stabilization of spent ore and associated acid rock drainage at the Intera and Green Springs area. ¹⁶⁶ The Order requires the mine to "submit a plan by May 11, 2010 stating whether the Mill-Water Ponds, the overhead standpipe near the Mille-Water Ponds, and any other leaking pipes or tanks in the area, will remain on the Liberty Dump or be moved off the Liberty Dump (and any other potential sources). If the Mill-Water Ponds will remain on the Liberty Dump, specify whether they will be replaced, or tested and repaired to demonstrate integrity of primary and secondary liners. If the ponds will be tested and repaired to demonstrate integrity, include a complete description of the proposed methods to be used for NDEP review and approval."
Tailings spills and impoundment failures	Tailings spill (see above)
Impacts to water, fish and wildlife	Contamination of downstream drainage bed for 2.3 miles from mine tailings process water. (See above)

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

TYRONE MINE, NM (Freeport McMoRan) The Tyrone Mine is located approximately 10 miles southwest of Silver City, New Mexico. The mine straddles the Continental Divide.	
Reports of pipeline failures and other accidental releases*	2006: Report of a spill occurring when a CTI tanker truck loaded with about 3,000 gallons of acid collided with a pickup truck, spilling about 500 gallons of the acid on the highway and adjacent property.¹⁶⁷ (non pipeline) 2003: Report of approximately 2,600 gallons of 16% sulfuric acid solution spilled at the Tyrone mine during maintenance activity on a pipeline system.¹⁶⁸ 2001: Report of 500-1000 gallons of solution leaked from the pipeline.¹⁶⁹ 2001: Report of 300 gallon spill of raffinate and organic solution from pipeline. 2001: Report of 150 gallon spill from the Seep 5# pond, which overflowed with 75 gallons entering Deadman Canyon. Seepage had a pH of 4 and Deadman Canyon was flowing at approximately 50 gpm at the time.¹⁷⁰ 1997: Report of 65,000 gallons of raffinate leaked from a ruptured weld in a raffinate pipeline.¹⁷¹ 1997: Report of a transfer line rupture due to cold weather. 1994: Report of No. 2 diesel fuel oil from two broken pipes detected in groundwater.¹⁷² 2012 report identifies diesel fuel contaminant concentrations in groundwater from a leak in distribution pipeline at diesel tank farm, which migrated to regional aquifer.¹⁷³
Water collection and treatment failures	In 2011, the U.S. Department of Justice and State of New Mexico issued a consent decree for damages to natural resources from hazardous substances from the Tyrone, Chino, and Cobre mines.¹⁷⁴ The settlement followed an investigation of natural resource injuries related to the release of hazardous substances into the environment from acid mine drainage and process solution, among other sources.¹⁷⁵ According to the investigation, "groundwater in both the regional aquifer and the perched groundwater aquifers at the site have been exposed to hazardous substances through a variety of pathways."¹⁷⁶ The assessment at the Tyrone Mine identified 14 different mine area sources that have affected water quality, including seepage from tailings impoundments, leach stockpiles and waste rock stockpiles. A 2012 groundwater assessment concluded that contaminated seepage from the mine will require water treatment in perpetuity.¹⁷⁷
Tailings spills and impoundment failures	There have been multiple spills of tailings, releasing hazardous substances. The largest event occurred at the No. 3 tailings dam in 1980, spilling 2.6 million cubic yards of tailings into the Mangas Valley.¹⁷⁸ Tailings flowed 8 kilometers downstream and inundated farmland.¹⁷⁹ The failure occurred due to a dam wall breach. 2001: 5 tons of tailings spilled into the Mangas Wash from the stormwater containment dike at the tailings dam.¹⁸⁰ 1990: Minor tailings spills from the No. 1 tailings pond in January 1990, and similar minor spills from the No. 2 tailings pond during 1990.¹⁸¹
Impacts to water, fish and wildlife	Streams and washes in the vicinity of the Tyrone Mine facility are ephemeral – they flow only after significant precipitation events. According to the 2003 preliminary assessment, "Surface water is exposed to hazardous substances released from the Tyrone Mine through a variety of pathways. Mangas Creek,

	an ephemeral stream adjacent to the Mine, which becomes perennial at Mangas Springs has been exposed to hazardous substances through spills and potentially through runoff and erosion.”¹⁸² The areal extent of the contaminated groundwater plume at the Tyrone Mine is 6,280 acres.¹⁸³ Groundwater seepage will require water treatment in perpetuity (see above).
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*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

MIAMI MINE, AZ (Freeport McMoRan; formerly owned by Phelps Dodge and Cyprus Amax Minerals) The Miami Mine is an open pit mine located 90 miles east of Phoenix, Arizona.	
Reports of pipeline failures and other accidental releases*	2011: Report of 1,600 pounds of sulfuric acid spilled from pipeline due to faulty weld.¹⁸⁴ 2009: Report of 1,000 pounds of sulfuric acid spilled due to pipeline break.¹⁸⁵ 2007: Report of a release of 9,450 pounds of sulfuric acid from pipeline.¹⁸⁶ 2001: Report of a release of 153 pounds and 6.4 pounds respectively of lead/arsenic from pipeline.¹⁸⁷ 2001: Report of a release of 2,070 pounds of acid plant blowdown from pipeline.¹⁸⁸ 1997: Report of 10,000 gallons of copper sulfate due to overflow of tank.¹⁸⁹ 1996: Report of 50,000 gallons of sulfuric acid due to tank failure.¹⁹⁰ 1996: Report of 8,995 pounds of sulfuric acid due to leaky pipe.¹⁹¹
Water collection and treatment failures	The Pinal Creek drainage was designated a Water Quality Assurance Revolving Fund (WQARF) site by the Arizona Department of Environmental Quality in 1989 due to acidity and metals contamination in the alluvial aquifer. The WQARF program is the state equivalent of the Federal “superfund” program. The Miami Mine, inherited from the Cyprus Miami Mine (formerly the Inspiration Mine) is a member of the Pinal Creek Water Quality Assurance Revolving Fund (WQARF) Site.¹⁹² The Pinal Creek site was listed under the Arizona Water Quality Assurance Revolving Fund program in 1989 for contamination in the shallow alluvial aquifers within the Pinal Creek drainage near Miami, Arizona.¹⁹³
Impacts to water, fish and wildlife	The Water Quality Assurance Revolving Fund (WQARF) program is the state equivalent of the Federal “superfund” program. The Miami Mine, inherited from the Cyprus Miami Mine (formerly the Inspiration Mine) is a member of the Pinal Creek Water Quality Assurance Revolving Fund (WQARF) Site.¹⁹⁴ The Pinal Creek drainage was designated a WQARF site by ADEQ in 1989 due to acidity and metals contamination in the alluvial aquifer.¹⁹⁵

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

SILVER BELL MINE, AZ (ASARCO) The Silver Bell Mine is an open pit copper mine located on the southern edge of the Silver Bell Mountains.	
Reports of pipeline failures and other accidental releases*	2010: Report of 3,983 pounds of sulfuric acid released due to pipeline failure. ¹⁹⁶ 2006: Report of 90,000 gallon release of raffinate; a mixture of 5.5 grams per liter of sulfuric acid and various metals. The release was due to equipment failure of a 24-inch mining pipeline. ¹⁹⁷ 2002: Report of 242,000 pounds of process solution (with 1300 pounds of sulfuric acid) spilled due to power failure and overflow of solution pond. ¹⁹⁸
Water collection and treatment failures	In 2009, Silver Bell was fined \$170,000 for three spills totaling 340,000 gallons of wastewater containing sulfuric acid and heavy metals into dry washes.¹⁹⁹ The pollutants seeped into soil, which endangered the groundwater in the aquifer below the mine and exceeded water quality standards. Two of the spills are described as such: Between Nov. 6 and Dec. 11, 2006, 150,000 gallons of leach solution containing sulfuric acid and metals escaped from a leaking impoundment. And between Nov. 11 and Dec. 13, 2006 another 100,000 gallons of stormwater containing sulfuric acid and heavy metals escaped from a storage pit. According to an EPA report, during site inspections of the mine in January and March 1993, the Arizona Department of Environmental Quality (ADEQ) observed water flowing in three unnamed washes below Silver Bell Mine.²⁰⁰ Samples taken from the two streams flowing under the waste rock dump showed violations of standards for total selenium, with one stream also violating standards for dissolved copper. The third stream, which flows from the leach dump, showed a broader range of exceedances, and concentrations of copper in this stream were several orders of magnitude greater than the concentrations in the other streams. Analyses showed violations of standards for pH, total zinc, total cadmium, and dissolved copper.
Tailings spills and impoundment failures	Tailings spills (See below).
Impacts to water, fish and wildlife	According to a 2000 report on native fish populations by Pima County, "The loss of native fish along Cocio Wash is a good example of the potentially damaging effects that mining can have on aquatic ecosystems. Summer floods in July and August 1981 swept gray clay sediments from a Silverbell Mine tailings pond into the wash. BLM biologist Bill Kepner later reported, Our studies indicate that the Cocio Wash topminnow population is now extinct in that habitat due to recurrent mine spills and inundations by mine tailings... (Fonseca, 2000)." ²⁰¹

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

MINERAL PARK MINE, AZ (Mercator) Mineral Park is an open pit copper mine in the Cerbat Mountains near Kingman, AZ.	
Reports of pipeline spills and other accidental releases*	1996: Report of 150 - 200 gallons of sulfuric acid released from acid storage tank due to equipment failure. ²⁰² 1996: Report of 200 gallons of sulfuric acid released. ²⁰³ 1996: Report of 1,100 gallons of sulfuric acid spilled. ²⁰⁴
Water collection and treatment failures	According to a 1995 report by the Arizona Geological Survey, water quality samples were taken of streamflow just below the Mineral Park mine and of mine water seeping through a dam at the southwest end of the tailings.²⁰⁵ Both samples showed extremely low pH values (3.2, 2.6), extremely high TDS values (5,549 and 6,625 mg/L) and extremely high sulfate contents (4,500 and 6,000 mg/L). According to the report, "the cadmium concentration of the stream flow just downstream of the Cyprus Mineral Park Mine place is 75.4 times higher than the standard, copper exceeds the standard 51 times and zinc 17.2 times." It further states that, "The discharge from the tailings ran down the washes until about two years ago, when the dam around the tailings was built. In years with very heavy rains the water could eventually reach the Sacramento Wash."²⁰⁶ According to a 1999 EPA report, the Mineral Park Mine collected surface water samples from seven drainages and analyzed them for metals and radio-chemicals.²⁰⁷ All of these drainages, except for Golden Eagle Spring, exceeded either the federal Maximum Contaminant Levels (MCLs) and or state guidelines for gross alpha or gross beta. According to the report, "ADEQ observed that surface water runoff emanating from the drainages in the mine area were affecting the water quality of the alluvial pediment." Data showed that the plume contained high levels of beryllium, cadmium, fluoride and nickel. The report further stated that, "the data show that TENORM is discharging from abandoned mine adits and is impacting surface water and that mining operations have impacted groundwater."²⁰⁸ A 2006 technical feasibility report commissioned by the company also describes a plume of contaminated groundwater migrating down-gradient from the mine.²⁰⁹
Impacts to water, fish and wildlife	See above.

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

CONTINENTAL PIT MINE, MT (Montana Resources) The Continental Pit is immediately adjacent to the Berkeley Pit in Butte Montana, and was initially known as the East Berkeley Pit. The Berkeley Pit and Continental Pit are included within the boundaries of the Silver Bow Creek/Butte Area Superfund site, which was established in 1983. Mining in the Berkeley Pit was discontinued in 1982, and in the East Berkeley Pit (now the Continental pit) in 1983. Mining was resumed in the Continental Pit by Montana Resources in 1986.²¹⁰ Because of their proximity, management of water and mine waste at the two mine sites are closely intertwined.	
Reports of pipeline spills and other accidental releases*	On January 28, 2009, an incident was reported to the Department involving a broken tailings line while crews were doing maintenance. The cause was attributed to a tailings line that was plugged with ice and a weld broke. The water was shut off within five minutes and no water left the site or reached state waters.²¹¹ 1992: Department records show an accidental release of 0.34 million gallons in August of 1992.²¹²
Water collection and treatment failures	According to a 1993 report, the sources of groundwater contamination in the Butte Mine Flooding Operable Unit of the Superfund Site were identified as: the underground workings; the walls of the Berkeley and Continental Pits; mine water in the underground workings; waste rock and tailings piles near the Berkeley Pit; leaking solutions from the leach pad and the Weed/MR Concentrator areas; leaking solutions from the Yankee Doodle Tailings Pond; contaminated soils and alluvium, and sulfuric acid added to the underground mines for copper leaching. Sources of water containing hazardous substances include: 1) process solutions from the historic Weed Concentrator and the current MR Concentrator.²¹³ Montana Resources suspended mining in the Continental Pit from 2000-2003 due to rising electricity costs.²¹⁴ During that time, about 7.5 billion gallons of water, or an average of 6 million gallons per day, went into the Berkeley Pit, to be combined with the highly acidic pit water already there. Montana Resources also diverted water from the Continental Pit into the Berkeley Pit for containment during their suspension. This contributed to increased water levels in the Berkeley Pit, and triggered the need to develop a water treatment plant to treat the contaminated water from the pit, which was rising to a critical level where contaminated pit water becomes an additional source of contamination to the surrounding aquifer and Silver Bow Creek. Under a consent decree with the State of Montana and US Department of Justice, a treatment plant was constructed and the mining companies are obligated to continue water treatment in perpetuity to prevent additional groundwater contamination.²¹⁵ Mine tailings from the Continental Pit mine are placed in the Yankee Doodle tailings impoundment, which also contains the mine waste from previous mining at the Berkeley Pit. The tailings impoundment is unlined, and seepage from the impoundment travels through faults and fractures into the Berkeley Pit. When mining ceases, seepage from the tailings impoundment will continue to contribute contaminated water to the Berkeley pit. As noted above, a consent decree requires contaminated water from the Berkeley Pit to be collected and treated in perpetuity.

*Limitations in the data for pipeline spills and other accidental releases make it difficult to determine, in some cases, whether water quality impacts resulted from the spill.

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Sulfide-Ore Copper Mining
and/or
A Sustainable Boundary Waters Economy:
The Need to Consider Real Tradeoffs

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Research and strategy for the land community.

EXECUTIVE SUMMARY

The USDA Forest Service is considering how to analyze the environmental impacts of the proposed withdrawal, for up to 20 years, of 234,328 acres of federally-owned lands within the watershed of the Boundary Waters Canoe Area Wilderness (BWCAW) from the federal mining program (USDA Forest Service, 2017). Because environmental impacts include effects on the economy, the question of how many jobs might be created by new mining activity in the Arrowhead region (defined here as St. Louis, Lake, and Cook Counties, Minnesota) is important. Equally important, but something that has so far been lost in the debate, is how many jobs and how much income in other sectors, and how much economic value that may not show up in job and income statistics—what economists refer to as “non-market” value (Stout, Winthrop, & Moore, 2015)—could be destroyed by the introduction of novel mining activity.

Proponents of *sulfide-ore copper mining* argue that the choice between this new type of mining and amenity-based development is a false choice for the Arrowhead region (Praxis Strategy Group, 2017). Those making this claim point to the continued existence of the *taconite mining* industry during the now decades-long expansion of amenity-based development in the region as proof that northeastern Minnesota can, in essence, “have it all.” According to this argument, the region can gain a relative handful of higher-paying jobs in mining; it can continue to have an abundance of high-quality recreational, scenic, and environmental amenities; and it can have jobs, income, and quality of life that exist in the region because of those amenities.

If the proposed sulfide-ore copper mining raised only the same environmental concerns as taconite mining and/or the sulfide ores were located as far away from the Boundary Waters as taconite mining and not within the BWCAW watershed, this argument might warrant consideration. But sulfide-ore copper mining presents more serious risks, such as acid mine drainage, and it would introduce risks in and around the Boundary Waters—the area that represents and produces those high-quality natural values that are the foundation of the region’s new economy. It is therefore far more likely that the “false choice” argument is itself false. There are two primary reasons:

First, the “we-can-have-it-all” claim relies on a distorted picture of the economy in which the size and importance of mining is inflated relative to the size and importance of the amenity-based development that sulfide-ore copper mining may disrupt. This distorted picture comes from studies that focus only on the economy’s exports (whether mining or tourism experiences) to the exclusion of other important facets of the economy. Those studies rely on a model of economic development that is decades, if not generations, behind the times. The studies incorrectly assume that only sales to buyers from somewhere else—for example, a steel mill or a vacationer from out-of-state—bring revenue to or support jobs in the local and regional economy. Such studies count jobs in the mines or at a resort, but they ignore jobs and income that exist in Arrowhead region due to what is known as “amenity-based development.”

Amenity-based development is economic activity in a host of industries, including recreation/tourism, construction, personal and professional services, retail, and others that arrives or stays in a region for the sake of its scenic, recreational, environmental, and quality-of-life amenities. These amenities induce an in-migration (and support the retention) of human capacity (entrepreneurs, skilled workers) that is the real engine of economic development. Amenities also attract and retain consumers, including retirees and working-age people who could do their jobs anywhere, but who would prefer to live in a place with a high quality of life.

In a world where many jobs can be done from almost anywhere, economic research must begin with an understanding of what it is that makes people choose any given location. This is not to say that the presence of a raw material is immaterial, but it does mean that, as in the days of classical economists David Ricardo and Adam Smith, one needs to pay attention to all of the factors that bestow comparative advantage on a region.

The economy of the Arrowhead Region has moved away from dependence on mining and now has a more diverse and stable economy. This has been particularly true since the early 1980s when steel manufacturing in the United States experienced significant declines that reduced demand for iron ore, including from the Arrowhead region. Structural changes in American industry, improvement in transportation, shipping, and communications networks, and new ways of hiring, working, and living have meant changes, described below, in the Arrowhead region similar to those seen in many high-amenity areas around the country. Increases in recreation and tourism are a big part of those changes, but so is the ability of people to locate their businesses and themselves where they will. While the Arrowhead still has taconite mining, forest products, manufacturing, and other “goods-producing” industries, it now relies predominately on environmental amenities and the quality of life to attract and retain business owners, workers, visitors, and retirees. Those who choose the region create and/or support jobs in diverse industries, including construction, manufacturing, recreation services, lodging and dining, and personal, professional, and educational services.

Second, the “we-can-have-it-all” claim is based on a false assumption that all mining, no matter what type or where it occurs, is compatible with all recreation, tourism, and other amenity- and/or quality-of-life-driven development. Taconite mining (particularly in places farther away from the BWCAW, its gateway communities, and from watersheds that give the Boundary Waters its name and its scenic and environmental quality) is not the same as sulfide-ore copper mining in the Boundary Waters watershed, on those communities’ doorsteps, and among the homes and businesses that exist where they do because of that scenic and environmental quality.

It is certainly true that amenity-based development has accelerated in the Arrowhead region while mining employment has continued (albeit at a much lower level), but it does not mean that further mining for different ores and with different environmental effects would not dampen or reverse that development. Indeed, as our preliminary investigation and scenarios reported below suggest, the introduction of sulfide-ore copper mining could cost the region the unique resources that are the basis for its sustainable economic development.

In this report, we review the composition of the Arrowhead Region’s economy as it has evolved over the past several decades. We demonstrate that demographic, employment, and income trends are consistent with a now-established understanding of how rural economies actually grow. In a nutshell, people follow amenities, and jobs follow people. Or, as McGranahan, Wojan and Lambert (2010) conclude, there is a “trifecta” of attractive outdoor amenities, creative workers, and entrepreneurship strongly associated with employment and business growth in areas that would otherwise face difficult economic challenges.

Regional economic trends, explored in detail in the body of this report, are consistent with this dynamic. The Arrowhead region has seen

- steady growth in population (after an early-1980s decline),
- steady increases in employment and personal income in diverse industries,
- growth in proprietors’ employment and income, and

- increases in non-labor income (such as investment income and Social Security payments) from people who may be living in or coming to the region to retire.

Looking forward, we also consider how these trends could change with the proposed advent of sulfide-ore copper mining in the watershed of the Boundary Waters. Based on information from business owners, retirees, and others, we consider how such mining, by changing the availability of attractive amenities and changing the quality of life, could change the trajectory for future prosperity in the region. We consider impacts on the recreation and tourism industry, on the broader amenity-based economy, and on the land values that may be diminished due to proximity to potential mining activity.

As explained below, based on conservative assumptions, sulfide-ore copper mining in the watershed of the Boundary Waters could bring the following effects for the three-county Arrowhead study region:

- \$288 million in lost visitor spending each year that would otherwise support
 - 4,490 local jobs
 - \$76 million in residents' income
 - \$31 million in state and local taxes, and
 - \$181 million in proprietor's income and business-to-business transactions
- 5,066 to 22,791 lost jobs, and between \$402 million and \$1.6 billion in lost annual income in the rest of the economy if sulfide-ore copper mining suppresses or reverses growth in the amenity-based economy that has been the backbone of the region's recovery since the early 1980s
- \$509 million in lost property value. This is a one-time drop in asset value that will spawn annual reductions in local property tax revenue throughout the Arrowhead region.

We do not claim that these estimates are complete. Indeed, we suspect that there may be threshold effects or feedbacks that would make actual effects much larger than what we have included in the scenario. Moreover, our estimates do not include the direct costs of long-term monitoring for, and attempts to mediate the occurrence of, acid mine drainage. Nor do they include direct impacts on local governments who may face higher road maintenance, water treatment, or other costs. The estimates developed here, therefore, should be taken as a first approximation of the sort of detailed analysis the Forest Service should complete as part of its Environmental Impact Statement examining the effects of the proposed withdrawal of federal land from the federal minerals leasing program, for a period of 20 years.

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Key-Log Economics remains solely responsible for the content of this report, the underlying research methods, and the conclusions drawn. We have used the best available data and employed appropriate and feasible estimation methods but nevertheless make no claim regarding the extent to which these estimates will match the actual magnitude of economic effects experienced if the Forest Service does not implement its proposed withdrawal of lands from the federal mining program.

THE ARROWHEAD ECONOMY

Area Overview

St. Louis, Cook, and Lake Counties make up what is called the Arrowhead Region of Minnesota (see Figure 1 below). This region boasts the natural beauty of forests and deeply interconnected streams, lakes, wetlands and groundwater. Beautiful destinations within the region include Voyageurs National Park, the Superior National Forest, and across the northern border of this region, the Boundary Waters Canoe Area Wilderness.

Reputed to be America's most visited wilderness, the BWCAW attracted 155,611 visitors in 2016 (The Wilderness Society, 2017; USDA Forest Service, 2017). The Boundary Waters contains 1.1 million acres of near-pristine water and unspoiled forests and wetlands that are as important to wildlife as they are attractive to people.

"Minnesota is known for its north woods and clean water. Those of us that live here value that and value the fact that we can vacation in our own back yard up north. Many people have cabins or lake homes in the northern part of the state. Many people dream to retire in the area. The state of Minnesota enjoys a very healthy diversified economy. I believe this is possible because of what our state has to offer to prospective businesses and talent they can bring to the state because of our quality of life."

--Retail Business Owner (Anonymous Survey)

Recreational resources include 1,200 miles of canoe and kayak routes, 1,175 lakes, 12 overnight hiking trails and more than 2,000 campsites (Ely Chamber of Commerce, 2016)

The Arrowhead Region's natural landscape attracts visitors who love to hunt, hike, camp, canoe, fish, and relax outdoors in a wilderness setting. As such, the landscape is vital to supporting the tourism industry of Northeastern Minnesota.

In addition, the Arrowhead Region of Minnesota exhibits what some researchers have termed "the rural growth trifecta"—a combination of outdoor amenities, creative workers, and entrepreneurship (McGranahan, Wojan, and Lambert, 2010). The area attracts retirees, seasonal residents, those working remotely (e.g., "digital nomads"), and entrepreneurs who could set up shop anywhere but who choose to do so in places with a high quality of life.

TRANSFORMATION OF THE ARROWHEAD ECONOMY, 1970-2015

The Arrowhead Region (St. Louis, Lake, and Cook Counties) in Northeastern Minnesota is home to a large taconite mining industry once understood to be *the* major driver in the local economy. In 1970, one in ten jobs and 15 cents per dollar of income earned were in the mining industry. Decline in the U.S.-based steel industry meant less demand for iron ore and, by the mid-1980s, the mining boom in the Arrowhead had ended. Automation has increased per-worker productivity, and mining's contribution to Minnesota's Gross State Product has stabilized, hovering around 1% over the past two decades (Cao and Tate, 2016, with Minnesota data downloaded from <https://bea.gov>). The other side of the productivity coin, however, has been a continued, steady decline in employment, and today fewer than 3 in 100 jobs and less than 5 cents per dollar in personal income is directly attributable to mining.

Beyond “Folk Economics”

If the traditional view or “mental model” of regional economic development were still applicable, the decline in taconite mining in the Arrowhead region would doom the region to long-term decline. But such a model is, at best, out of date, and any consideration of the region’s alternative futures must be grounded in mental model, or conception, of an economy built on fundamental values in addition to the sale of material goods to other regions.

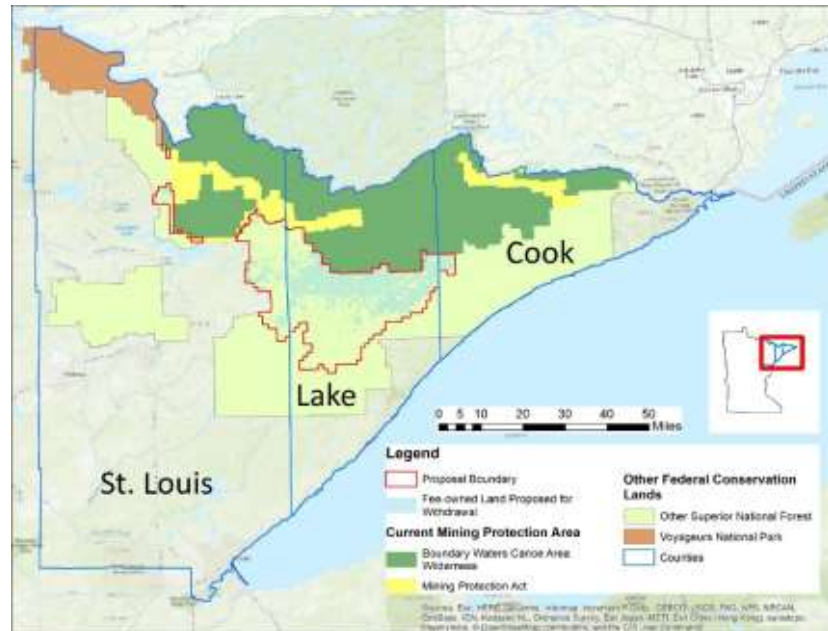
Dr. Thomas Power, in discussing the potential effects

of a copper mining operation in Arizona, explains how much of our popular understanding of how economies work is rooted in “the export base view of the local economy” (2010, p 4). In this view or model, people from the local or regional area grow crops, mine for minerals, harvest timber or otherwise extract a product from the land and then export that product to another region in exchange for cash. A slightly evolved version of this model recognizes that tourism is part of the “export base” along with other goods-producing industries. The only difference is that exporting an experience (i.e., tourism) requires the buyer to come to the region, leave his or her money behind, and then take the experience home with them. In this model, that initial export transaction is the basis for all other economic activity, because the farmer, the miner, the logger, and the tourism provider all have to employ local people as laborers and buy various goods and services from other local businesses. The lumberman may hire a trucking company and buy equipment, the farmer may hire a farmhand and buy seed, and the tourism provider hires staff and buys provisions to outfit visitors’ trips into the backcountry. Empirical versions of the economic base model, generically known as “input-output models” combine the effects of spending by the employees of the exporting businesses with spending by the employees of the businesses that serve the exporting businesses to generate estimates of “multiplier effects”. These multipliers purport to show how much “output” in the form of jobs or income the region gets as a result of the initial “input” of spending on the exported goods or services. There is a limit to these rounds of impacts, because eventually some business or household is going to IMPORT a good or service from somewhere else and dollars that had been circulating among local firms “leak” out of the local economy and go on to stimulate some round of spending in another region.

There are many things wrong with this conceptual model and many more wrong with the empirical input-output models used to estimate impacts and multipliers. Not least of these, are that the empirical models have little predictive power (Krikelas, 1991) even in cases ideally suited to their

Figure 1: The Arrowhead Region

Public Lands, including the Boundary Waters Canoe Area Wilderness, and Areas Proposed for Withdrawal from the Federal Mining Program.



Sources: USDA Forest Service; U.S. Bureau of the Census; ESRI base map.

underlying structure and assumptions (Roberston, 2003). It has been 32 years since H.W. Richardson looked and concluded that 40 years' experience with economic base models [to that date] "[had] done nothing to increase confidence in them". In addition, he concluded that it would be hard to "resist the conclusion that economic base models should be buried, and without prospects for resurrection (Richardson, 1985)." Nevertheless, consultants and others persist in using these models because they conform to faulty, "folk-economic" assumptions and they provide the impressive sounding answers that those promoting various development schemes, tax breaks, or other policies may want decision makers or the public to hear.

Fundamentally, however it is not the export of goods, services, or experiences that determines the economic fortunes of a region. Rather, it is the underlying productive capacity of all of the region's resources. It is the combination of natural capital with the creativity, energy, and spirit of the people occupying those places. (Natural capital capacity for natural systems to provide food, raw materials, clean water, pleasant scenery, and recreational opportunities, among other "ecosystem services" essential to the health and well-being of people (Farley, 2012))

If the economic base model's assumption that "people will simply go to where the jobs are" was true in the past, it is true no longer. Today, people can locate where they will, and given the choice, will go where the quality of life is high, even if that means accepting a lower cash income. Niemi and Whitelaw call this getting a "second paycheck" in health, recreational access and other values, that compensates for the income they give up by not moving to a less desirable location (1999, 18). (See also Roback (1982 and 1988) for earlier statistical analysis of this phenomenon.) Moreover, businesses are comprised of people, and the people who are business owners and managers often choose to locate their business in places that offer a high quality of life, and where they can find workers who appreciate that second paycheck.

Power (2010) puts it this way:

Areas that have mixes of qualities that make it easy for those areas to attract and hold residents, will have a relatively large, diverse, and skilled workforce available at a somewhat lower price. Alternatively, such areas can get workers to move to the area without wages being bid up significantly. That makes such areas attractive to businesses. The fact that businesses are run by people who also have preferences about where they and their families live, only adds to the economic importance of a community's attractive qualities (p. 3).

He concludes that an appropriate and adequate evaluation of the impact of economic changes (Power happened to be writing about potential copper mining as well) must consider the supply side of the labor market and not just the demand for labor "created" by export-oriented development. Because it is the supply of labor attracted to a region that matters most to the region's development, this newer model of regional development is typically called a "supply-side" model.

Amenity-based development has taken the place of mining as the engine of economic development in the Arrowhead region. Amenity-based development is economic activity connected to a region's scenic, recreational, environmental (clean air, clean water), and other quality-of-life assets. Amenity-based development extends far beyond the recreation and tourism industries to any good- or service-producing industry that sells homes, cars, personal or professional services, food, etc. to people who move to, or stay in, a region because of its scenic beauty, quality of life, and in the case of the Boundary Waters, unique, world-renowned recreational opportunities. Construction, medical and financial services, all manner of retail, and other diverse industries are all contributors to (and beneficiaries of) the amenity-based economy of the Arrowhead region.

This new economy still has an export component: when people from outside the region come to Ely or Grand Marais to visit, they take away the experience and the memory of the landscape, and share it with others who may be convinced to visit. Unlike mining, such use of the landscape's scenic, recreational, and other amenities can be repeated indefinitely without fundamentally altering the landscape or diminishing its capacity to supply similar values to future visitors or future generations. In other words, the Arrowhead's amenities are a resource much like minerals, with the important exception that amenities are not used up by use.

Key Trends in the Arrowhead Economy

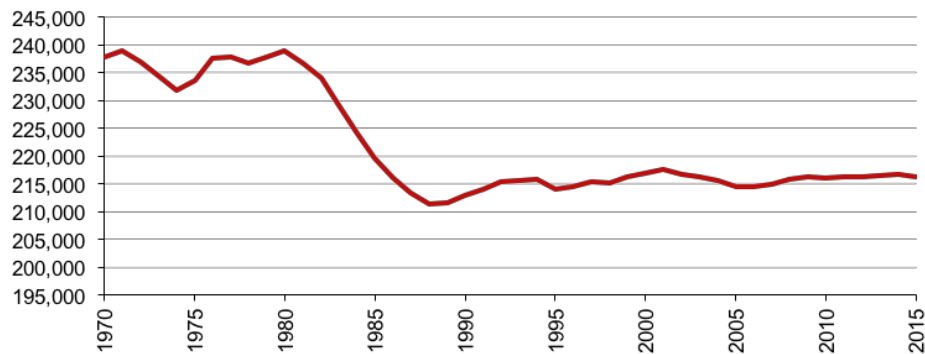
- The recession of the early 1980s coincided with a decline in mining from 10% of regional employment in 1980 to 2.5% in 2015.
- Services, including those directly connected to the region's high quality outdoor amenities (recreation and tourism) and those indicative of robust amenity-based development (construction, professional and other services) were already growing in the early 1980s and have continued to outpace all other sectors since.
- Today, more than 7 in 10 jobs are "services related."
- The fastest employment growth (since 2010) in the services category is coming from
 - information (up 13.4%)
 - professional services (up 12.3%)
 - real estate (up 12.1%)
 - educational services (up 10.0%)
 - arts, entertainment, and recreation (up 8.9%)
- The population of the three-county Arrowhead Region containing the Boundary Waters has been stable since 1990.
- Population, employment and income trends indicate the attractiveness of the Arrowhead Region to retirees and entrepreneurs.
 - Median age has increased and the largest increases in population have been among people 45 and older.
 - In 1980, sole proprietors represented slightly more jobs than mining. Today there are seven times as many proprietors as mining jobs.
 - Since 2000, growth in proprietors' employment has outpaced growth in wage-and-salary employment by a factor of 4.5 (10.3% in 2015, up from 2.3% in 2000).
 - While labor income has grown (by 8.8% since 2000), non-labor income from investments and transfer payments like social security have increased by nearly four times as much (by 33.3%).
 - Non-labor income accounts for 42% of all personal income in the region (up from 26% in 1970), with investment income and age-related transfers making up three quarters of non-labor income.
- Since the late 1980s, unemployment trends in the Arrowhead Region have tracked closely with those in the State of Minnesota as a whole.

Demographic Trends

Total Population: Decline and Regrowth

From 1970 to 2015, the total population declined from 237,809 to 216,256 people, with most of the change occurring between 1980 and 1988—a period of steep decline in mining employment. Since 1988, the population has rebounded, by 2.3% or 4,812 persons. However, from 1990 to 2014 the population of the three-county Arrowhead Region has been stable with modest growth of 2%. (See Figure 1.) (Note that these population estimates include only year-round residents, not seasonal residents.)

Figure 2: Population, Arrowhead Region, 1970 – 2015



Source: Headwaters Economics: Economic Profile System-
<https://headwaterseconomics.org/>; SocioEconomic Measures: Underlying Data Sources: U.S. Department of Commerce. 2016. Bureau of Economic Analysis, Regional Economic Accounts, Washington, D.C. Table CA30.

Age of the Population

The Arrowhead region's population is older, and, apart from St. Louis County, is getting older faster than the population of Minnesota as a whole. From 2000 to 2015, the median age in Minnesota and in St. Louis County increased by 2 years; in Lake and Cook Counties, the increase was 7 years. Within the Arrowhead region, there are fewer in the under 18 and 35-44-year-old age brackets, with gains coming in the 18-34, 45-64, and 65 and over brackets. While not definitive, the gains in the older two brackets, coupled with the region's rapid rise in age-related transfer payments (i.e., Social Security and Medicare payments—see below), suggest an increase in the number of people choosing the region for their retirement.

Figure 3: Change in Median Age, Arrowhead Counties and Minnesota, 2000 - 2015

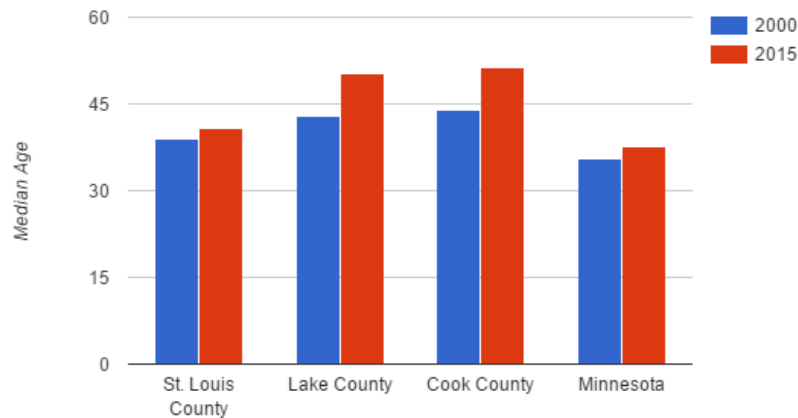
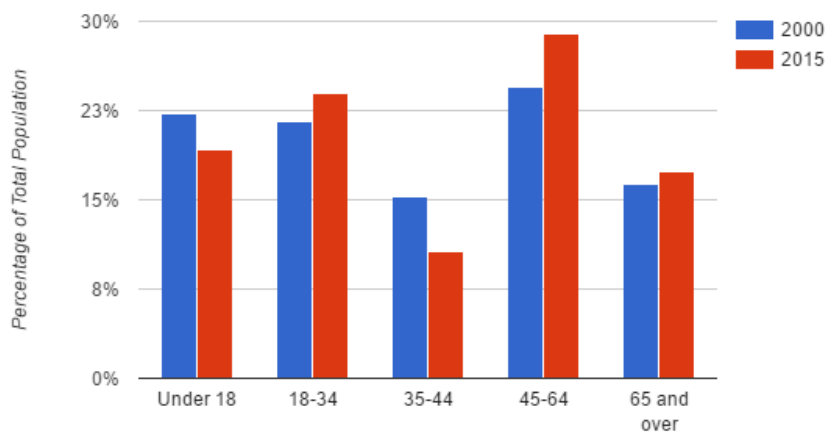


Figure 4: Age Distribution, Arrowhead Region, 2000 and 2015



Sources: US Census Bureau. (2017). American Fact Finder. Retrieved from <https://factfinder.census.gov/>; Headwaters Economics. (2017). Economic Profile System. Retrieved from <http://headwaterseconomics.org/tools/eps-hdt>

Housing

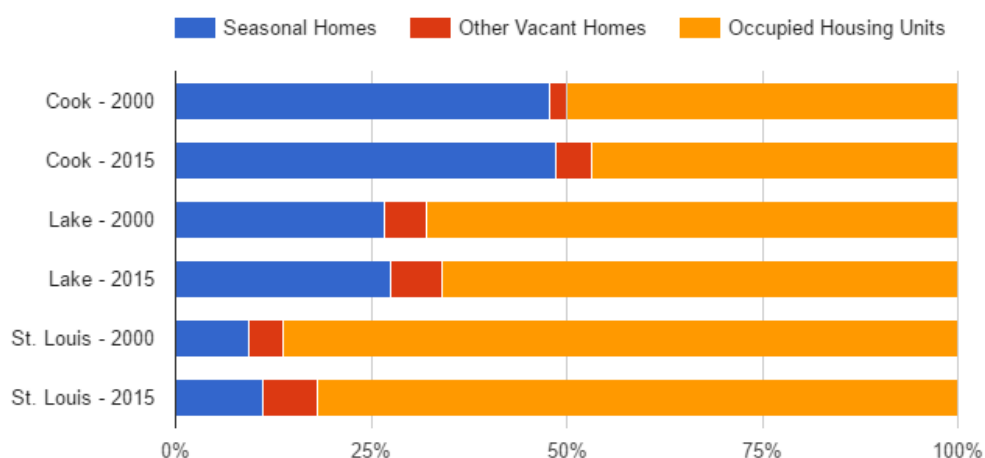
The Arrowhead region added almost 10,000 housing units (+8.6%) from 2000 through 2015. During the same period, the region's population was nearly flat (476 fewer people, or a decline of 0.22%). This seeming disconnect reveals two trends: more people are moving into their own housing units (as sign of increasing overall prosperity); and more people are building vacation homes in the region. In contrast to the 8.6% increase in overall housing units, the number of housing units for "Seasonal, Recreational, or Occasional Use" increased by 26% in the region. In Lake and Cook Counties vacation homes now comprise nearly one third and one half, respectively, of all housing units. St. Louis County, which has many more housing units to begin with, is adding vacation homes at the fastest rate (up 29% since 2000).

These housing trends illustrate the attractiveness of the region for regular visitors. It also helps explain some of the other trends we'll describe below, including increases in jobs and income in construction, real estate, and a host of other industries that people would use in the course of purchasing land,

building a home, and then using it repeatedly over the course of years. Groceries, utilities, home maintenance, health care while in the region, restaurant meals, and others are all part of the package when people invest in a region based on its quality of life.

The housing trends may also be a harbinger of still more future growth, if the current owners of homes for seasonal or occasional use become full-time residents. Some of these owners could be looking ahead to converting the homes for retirement use, and some may decide to move their job or business to the region. Either would represent important, long-term economic development opportunities for the Arrowhead region.

Figure 5: Housing Units by Type, Arrowhead Counties, 2000 & 2015



Sources: US Census Bureau. (2017). American Fact Finder. Retrieved from <https://factfinder.census.gov/>

Employment and Income

Unemployment Rate

In the mining bust of the early 1980s, unemployment rates spiked to nearly 20%. Since 1988, however, Arrowhead unemployment rates have remained much lower, and they have tracked closely with the statewide unemployment rate (Figure 6). This is consistent with what one would expect of an increasingly diverse economy. In another sign of increased resilience in the Arrowhead region since the late 1980s, recessions have not pushed unemployment as high and the recovery from them has been faster than before the mining bust (Figure 7).

Figure 6: Unemployment Rate, Arrowhead Region, 1976-2015

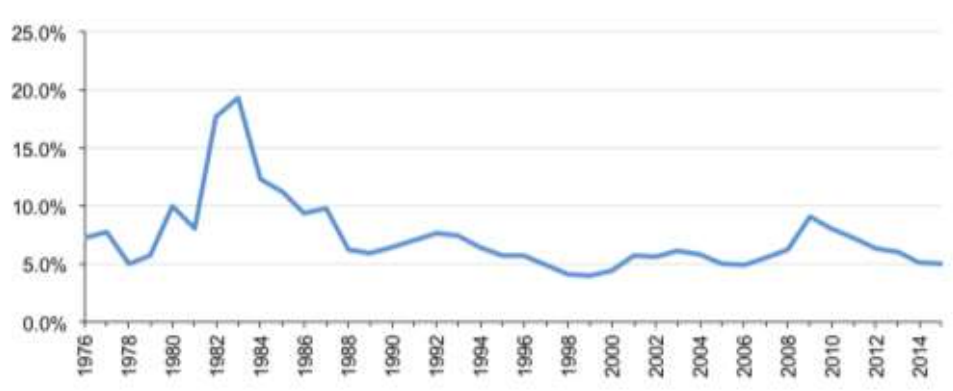
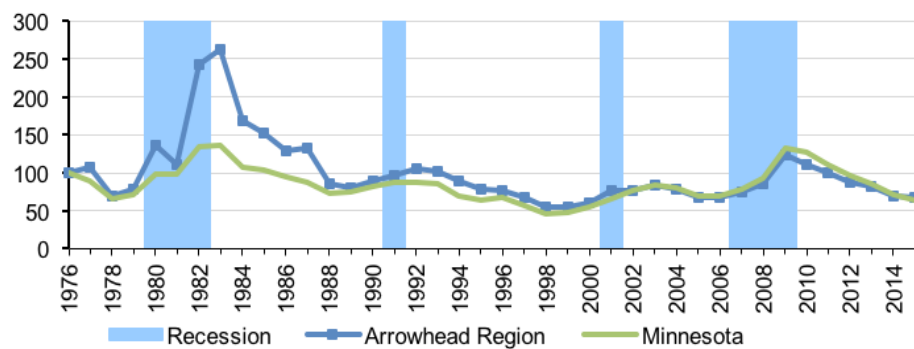


Figure 7: Unemployment Rate, Arrowhead Region and Minnesota, 1976-2015 (indexed with 1976=100)

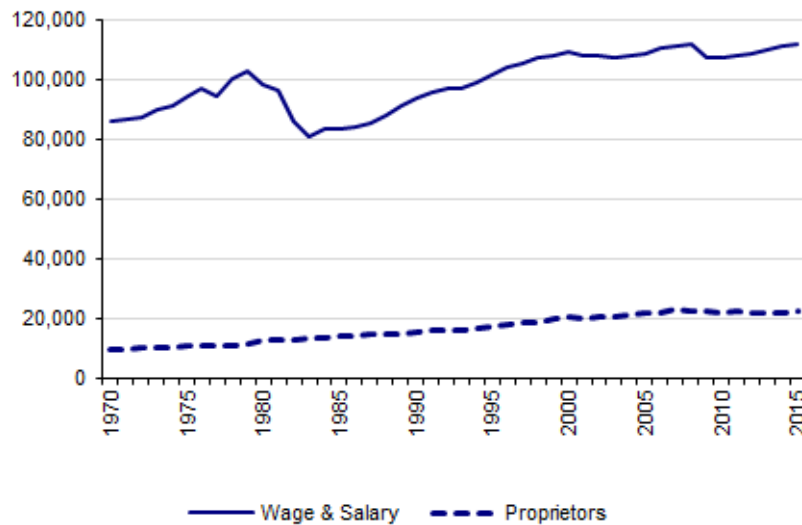


Source: Headwaters Economics: Economic Profile System- <https://headwaterseconomics.org/>: SocioEconomic Measures: Data Sources: U.S. Department of Commerce. 2016. Bureau of Economic Analysis, Regional Economic Accounts, Washington, D.C.; U.S. Department of Labor. 2016. Bureau of Labor Statistics, Local Area Unemployment Statistics, Washington, D.C.

From 1970 to 2015, total employment in the Arrowhead region grew from 95,516 to 134,402, a 41% overall increase that erased losses sustained due to the mining-led bust of the early 1980s. From 1983 to 2015 jobs grew by 39,933, a 42% increase. While wage and salary jobs (that is, working for someone else) are most common, proprietorships are growing faster--by more than 10% since 2000, compared to the 2.3% increase in wage and salary employment over the same period (Figure 8).

By 2015, one worker in six was self-employed. This concentration of proprietors indicates the region's "entrepreneurial breadth", which is one of several key rural assets that supports economic prosperity and resilience in today's global economy (Low, 2004).

Figure 8: Employment by Type, Arrowhead Region, 1970 - 2015



Source: Headwaters Economics: Economic Profile System-
<https://headwaterseconomics.org/>: Socioeconomic Measures Report: Data Sources:
 U.S. Department of Commerce. 2016. Bureau of Economic Analysis, Regional
 Economic Accounts, Washington, D.C. Table CA30.

Income by Source

The income earned by wage-and-salary workers and by proprietors is “labor income”, and that accounts for 58.3% of total personal income of Arrowhead region residents. The other 41.7% is “non-labor” income and is comprised of income from past investments (dividends, interest, and rent), plus transfer payments, like Social Security and Medicare. Non-labor income has increased by a third (33.1%) since 2000, while labor income has increased by just 8.8%. Because non-labor income is attached to a person and not to a job or company, this is an important part of a region’s economic engine, and may be particularly sensitive to changes in quality of life, including the availability of recreational and environmental amenities. People can retire where they want, and, other things being equal, they are more likely to choose places with a safe and pleasant natural environment.

Earnings per job and income per person tell a similar story. While average earnings are increasing for wage and salary employees in the Arrowhead region (Figure 10), average income per person is rising much faster. Like the demographic trends, this reflects an aging population with relatively more investment and retirement income.

Figure 9: Labor and Non-Labor Income, Arrowhead Region, 1970 - 2015

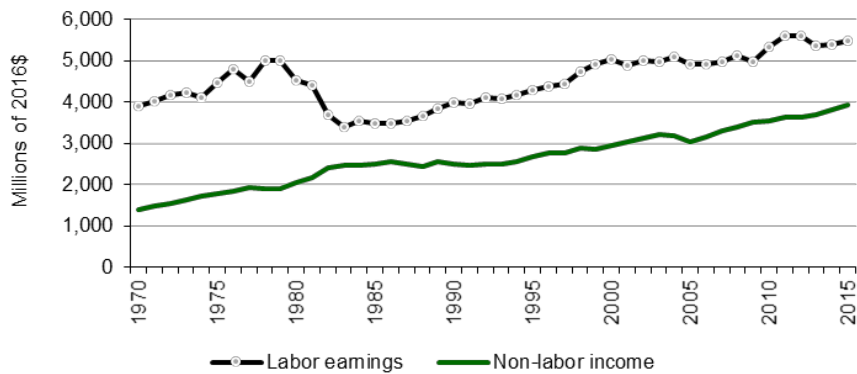
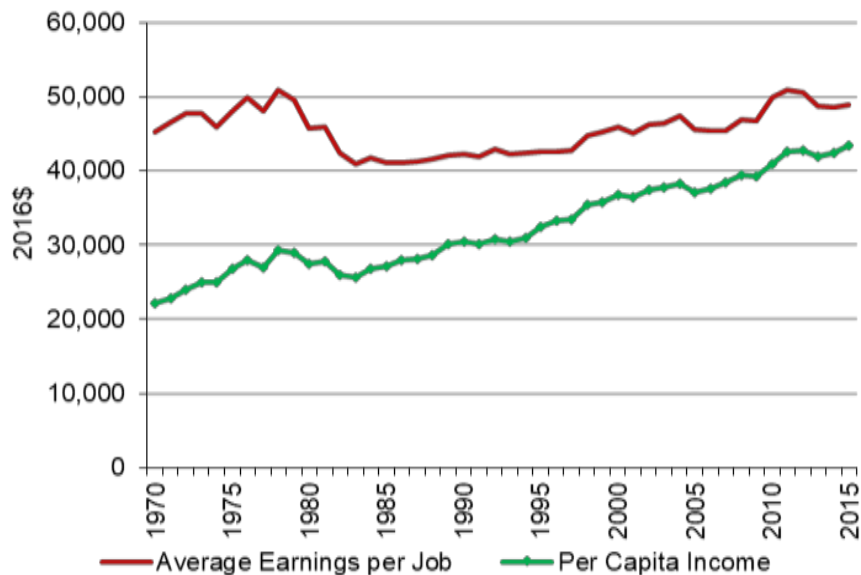


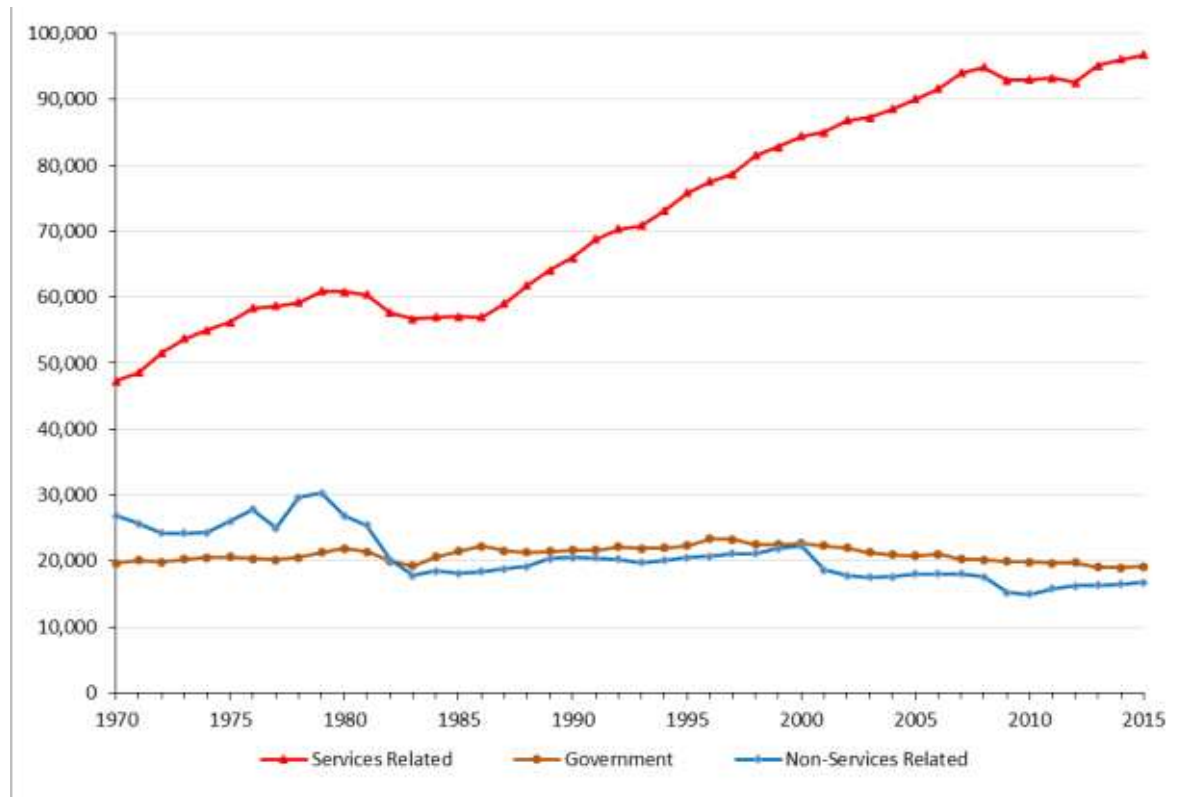
Figure 10: Earnings per Job & Per Capita Personal Income, Arrowhead Region, 1970 – 2015



Source: Headwaters Economics: Economic Profile System-
<https://headwaterseconomics.org/>: Socioeconomic Measures Report: Data Sources: U.S. Department of Commerce. 2016. Bureau of Economic Analysis, Regional Economic Accounts, Washington, D.C. Table CA30.

Employment and Income by Industry

Since the decline of mining in the early 1980s, total employment in the public sector and in the goods-producing industries (farming, mining, construction, and manufacturing as a whole) has remained flat, while employment in services has grown steadily. Today, almost three out of four jobs are in services, while only one in eight is in the goods-producing industries. There are differences among the industries that comprise these broad categories, however. For example, the region has seen steady increases in construction employment, which reflects the increases in housing stock already discussed. The effects of amenity-based development, in other words, are not restricted to the service-producing sectors.

Figure 11: Employment by Major Industry Category, 1970 – 2015

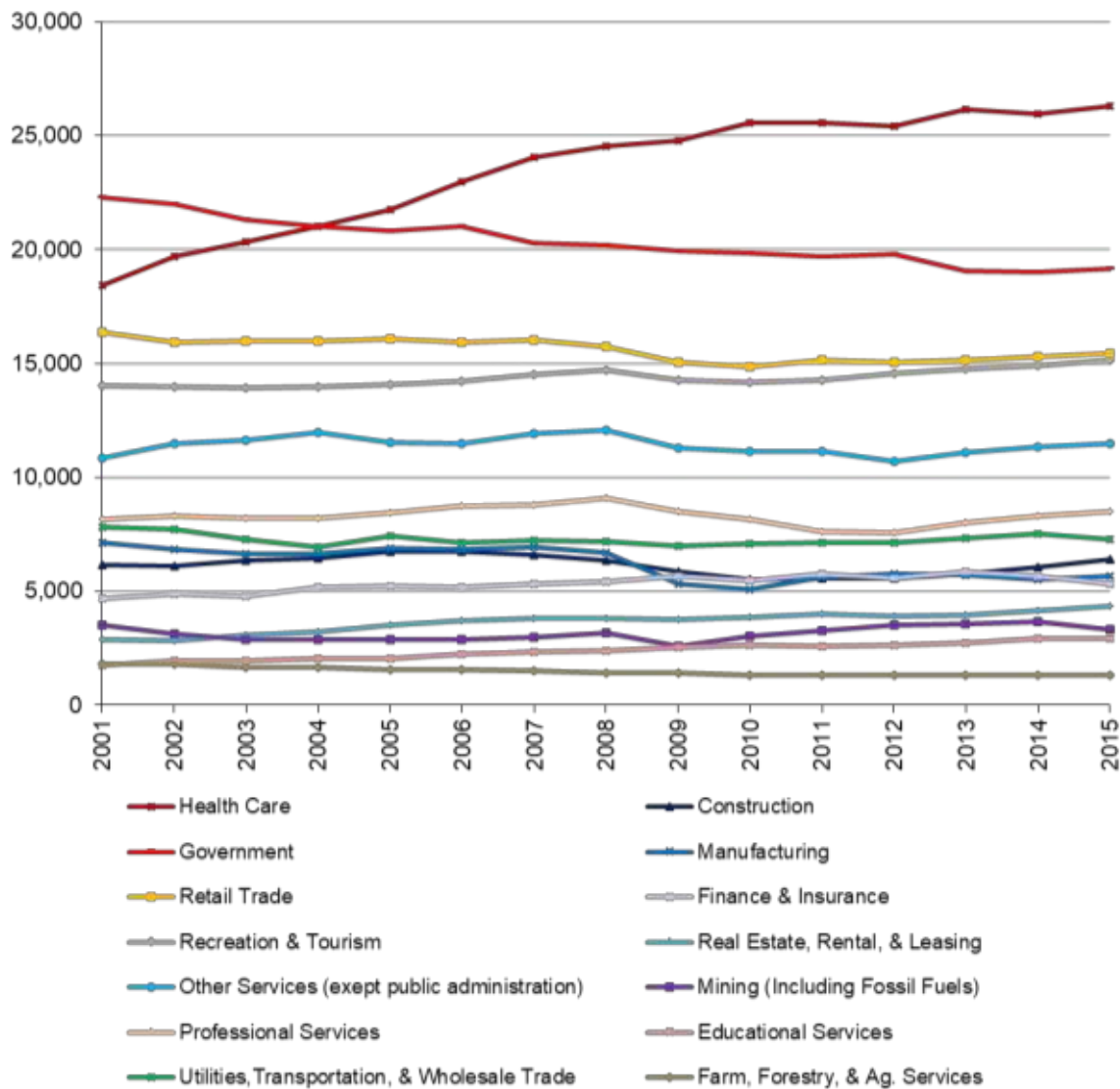
Source: Headwaters Economics: Economic Profile System- <https://headwaterseconomics.org/>; Socioeconomic Measures: Data Sources: U.S. Department of Commerce. 2016. Bureau of Economic Analysis, Regional Economic Accounts, Washington, D.C. Tables CA25 & CA25N. The series is split at 2000-2001 due to the changes in the classification of industries that does not allow direct comparisons of all data from before and after the change.

The steady increase in the number of jobs in service-related industries, coupled with the relative stability of the Arrowhead economy since 1988 indicates the extent to which the regional economy has moved beyond mining-dependence and does not need to favor the production of material goods for export to survive. (See “Beyond Folk Economics”, page 2.) Instead, the Arrowhead region has been able to recover and prosper on the basis of diverse economic activity, much of which is directly or indirectly related to the quality of the environment more broadly.¹

Recreation and tourism represents 11.3% of all jobs in the region, which are perhaps most closely tied to how visitors perceive and enjoy the region’s natural assets. Visitors also support local businesses in the retail trade (11.5%), real estate rental and leasing (3.2%), educational services (which may include camps if the camp owners self-identify their business as an education rather than a lodging business) (2.2%), and other industries. Given the number of firms making outdoor apparel and equipment, and other products used by visitors, recreation and tourism also supports and is tied to local manufacturing employment and income (4.2%).

¹ It is important to note, however, that there is significant variation among smaller geographic areas within the Arrowhead Region, and some communities are more or less dependent on goods-exporting industries versus service-producing industries.

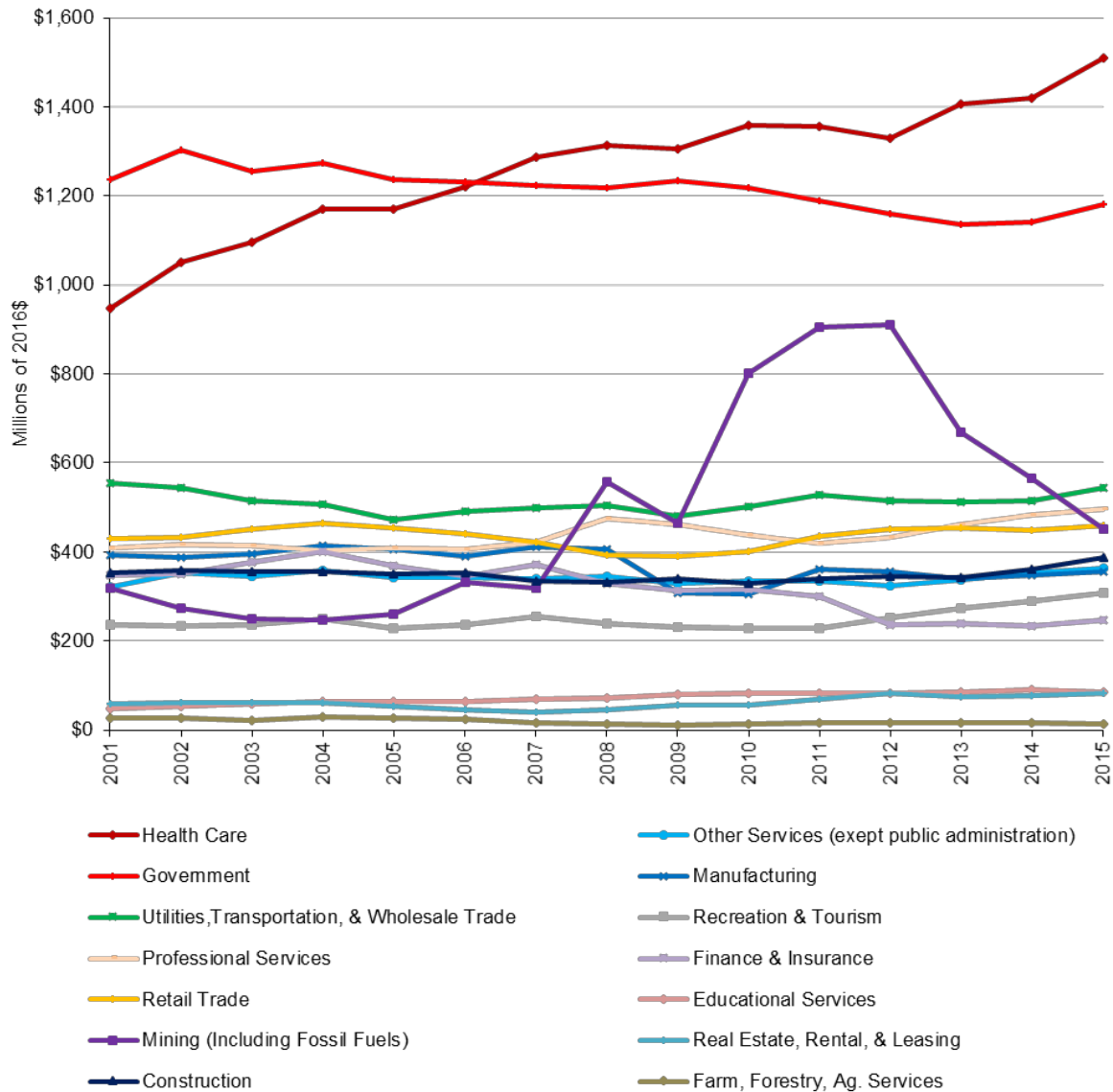
Figure 12: Employment by Industry Group, Arrowhead Region 2001 - 2015



Note: "Recreation & Tourism" includes Arts, Entertainment, and Recreation as well as Accommodation and Food Services. "Other Services" includes Other, Administrative, and Waste Services. "Professional Services" includes Professional Services, Management of companies and enterprises, and Information. "Utilities, Transportation, & Wholesale Trade" includes these categories and Warehousing. "Farm, Forestry, & Ag. Services" includes Farm, Forestry, Fishing, and Ag. Services.

Source: Headwaters Economics: Economic Profile System- <https://headwaterseconomics.org/>; SocioEconomic Measures: Data Sources: U.S. Department of Commerce. 2016. Bureau of Economic Analysis, Regional Economic Accounts, Washington, D.C. Tables CA25N.

Figure 13: Earnings of Workers, by Industry, Arrowhead Region, 2001-2015, Millions of 2016\$



Note: "Recreation & Tourism" includes Arts, Entertainment, and Recreation as well as Accommodation and Food Services. "Other Services" includes Other, Administrative, and Waste Services. "Professional Services" includes Professional Services, Management of companies and enterprises, and Information. "Utilities, Transportation, & Wholesale Trade" includes these categories and Warehousing. "Farm, Forestry, & Ag. Services" includes Farm, Forestry, Fishing, and Ag. Services.

Source: Headwaters Economics: Economic Profile System- <https://headwaterseconomics.org/>; SocioEconomic Measures: Data Sources: U.S. Department of Commerce. 2016. Bureau of Economic Analysis, Regional Economic Accounts, Washington, D.C. Tables CA05N.

Recreation-and-tourism-driven employment and income are just a portion of the region's amenity-based development, however. Retirees and entrepreneurs who move to the region for its quality of life are perhaps even more important, because they create and support jobs in the local and broader regional economy by using health care (19.6% of jobs), professional services (6.3%), financial services

(“Finance and Insurance”) (4%), as well as services of the construction and real estate industries (8% cumulatively).

These statistics alone do not tell us many of the people behind these employment figures are located in the Arrowhead region for the sake of its environmental and other quality-of-life amenities. It is clear from other sources of information, however, that such amenities are important to decisions to move to or stay in this particular region as well as in other similar high-amenity areas (Ronnader, Wente, and Hove, 2014; Florida, 2000; Niemi and Whitelaw, 1999; Northeastern Minnesotans for Wilderness 2016). Therefore, to mistake recreation-and-tourism as the sum total of amenity-based development would miss much of the contribution of natural capital to the Arrowhead Economy. By the same token, to compare employment, wages, and other economic impacts from mining to those in recreation and tourism alone, as in the report by the Praxis Strategy Group (2017), is to present a distorted picture of the full extent of the “opportunity cost”² of sulfide-ore copper mining.

Trends in earnings or income by industry, depicted in Figure 13, look much like the employment trend, with the largest share of income and some of the most rapid growth occurring in services. One relevant difference between graphs is that the pronounced boom and bust in mining *income* between 2008 and 2015 does not seem to have translated into much change in mining *employment* during that time. This suggests that while those with mining jobs do comparatively well in the boom times, the boom does not do much to increase the number of mining jobs.

Visitor Expenditures and the Tourism Industry

It should be clear by now that there are many facets to the amenity-based economy of the Arrowhead region. Tourism, however, is usually the first industry that comes to mind when one thinks about the impacts of potential land use change and loss of environmental quality. In this section, therefore, we focus on the various economic effects of the attractiveness of the Boundary Waters to visitors from other places.

Unlike “mining”, “construction”, “professional and technical services”, or other industries, there is not a single industrial classification into which all facets of the visitor services industry, or tourism as we will call it from here on, fits. Rather, the tourism industry is comprised of pieces of industries that, to varying degrees, serve visitors and residents alike. Air transportation, hotels and other lodging places, and some services might be used primarily by visitors. Restaurants, guiding and outfitting services, outdoor retailers, gas stations, and grocery stores, however, serve both residents and visitors. Estimates of jobs or income by industry, therefore, need to be augmented with other data in order to get a complete picture of the tourism industry, leavened with survey data reflecting how and where tourists actually spend their money.

Those who lose with sulfide-ore copper mining would be Arrowhead, Twin Cities, and other Minnesota residents who, perhaps having chosen their location to be near the amenities of the Boundary Waters, now have to spend more time and money to get to somewhere else.

² “Opportunity cost” is economists’ term for what a person or the economy as a whole inherently loses in making a choice between competing options. In this case, the opportunity cost of sulfide-ore copper mining would register as jobs and income in the amenity-based economy, along with other values.

Davidson-Peterson Associates conducted such a survey of visitors for Explore Minnesota Tourism in 2007 and 2008 and developed county-by-county estimates of traveler expenditures in Minnesota and the jobs, state and local tax revenues, and other impacts those expenditures support (Davidson-Peterson Associates, 2008). Of Minnesota's 87 counties, St. Louis, Cook, and Lake Counties ranked third, thirteenth, and sixteenth from the top in terms of in-county traveler expenditures. The total for the Arrowhead region in 2008 was \$1.1 billion (adjusted for inflation to 2015 dollars). These expenditures supported almost 15,800 full-time equivalent jobs, nearly \$300 million in workers' income, and \$119 million in state and local tax revenue (all in 2015 dollars). The balance, roughly \$700 million, went to other businesses and to owners of the direct tourism businesses.

To gain a more current picture of these contributions to the Arrowhead region's economy, we turn to another Explore Minnesota report conducted by Tourism Economics (2016) which estimated year-by-year expenditures and other metrics for the entire state. According to the report, statewide visitor expenditures grew at an average annual rate of 4.97% from 2009 to 2015. Starting from the 2008 base for the Arrowhead region and applying the year-by-year growth rates for the entire state, we estimate that expenditures in the Arrowhead region would have been \$1.42 billion in 2015, which would have supported 22,174 full-time-equivalent jobs, \$376 million in resident's income, and \$152 million in state and local tax revenue.

It is important to note that these estimates reflect only those expenditures by out-of-state visitors. Minnesotans residing outside the Arrowhead who visit the region to recreate in the Boundary Waters, as well as Arrowhead region residents who recreate close to home, add to the expenditure totals and further support the region's tourism industry. As discussed under "Beyond Folk Economics" (on page 2), such expenditures by in-region or in-state residents may not be considered a true economic impact because the dollars spent are already there. We contend, however, that those expenditures should be counted as part of the economic contribution of the Boundary Waters and of the natural amenities of the Arrowhead region. The reason is that Arrowhead residents and all Minnesotans can choose where to spend their recreation and tourism dollars. If sulfide-ore copper mining were to make the Boundary Waters less suitable or attractive a place to spend one's time and money, then some portion of those expenditures by Minnesotans would occur somewhere else. The Arrowhead region would lose, and another region, perhaps one that had not sacrificed its wilderness character or environmental quality, would gain. Among the losers, of course, would be those Arrowhead, Twin Cities, and other Minnesota residents who, having chosen their location to be near the amenities of the Boundary Waters, would now have to spend more time and money to get to somewhere else.

Seasonal Residents

As the information on seasonal housing on page 6 indicates, the Arrowhead region has many part-time or seasonal residents. A recent study of four townships³ by the University of Minnesota, Morris' Center for Small Towns (2014) reveals that seasonal residents spend an average of \$8,008 per household per year (in 2015 dollars) in the local economy. If this average is typical of the 16,357 vacation/seasonal homes across the Arrowhead region, seasonal residents would contribute some \$131 million per year to the region's economy. This spending supports businesses and employment in all industries, including construction, automotive service, medical, retail, and entertainment.

³ The townships included in the study are Morse, Fall Lake, Stony River, and Eagles Nest.

POTENTIAL EFFECTS OF SULFIDE-ORE COPPER MINING ON THE ARROWHEAD REGION'S ECONOMY

The current dominant narrative from proponents of sulfide-ore copper mining seems to be focused on predictions of new jobs and economic prosperity due to new mining activity without any consideration of the magnitude of the economic costs. Indeed, proponents of sulfide-ore copper mining, by claiming the region can “have it all”, espouse a view that there would be no costs at all.

Proponents of sulfide-ore copper mining would do well to recall the famous aphorism from Nobel Laureate Milton Friedman: “There is no such thing as a free lunch.” Decision makers, in other words, should not forget that there is an “opportunity cost” to the introduction of sulfide-ore copper mining into the watershed of the Boundary Waters. This cost includes lost visitor spending and the jobs and income associated with it, lost economic development throughout the economy as sulfide-ore copper mining makes the region less attractive as a place to live and do business, and lost property value as residents flood the market with first and second homes located in places where it is no longer desirable to visit or reside.

We therefore provide the following preliminary estimate for some of these key economic costs of sulfide-ore copper mining. We want to emphasize, however, that our estimates reflect only impacts on a limited number of **market** values (property value, jobs, and income) and are, therefore, very conservative estimates of the full **economic** value at stake. Economics recognizes that the dollars that change hands in the marketplace (or don't change hands, as would be the case with sulfide-ore copper-mining-induced changes in the Arrowhead economy) are just a partial indicator or reflection of the total economic value of natural resources and the environment. For every dollar paid in market value, such as for travel or lodging to recreate in the BWCAW, to buy hard goods and provisions for the trip, or to buy a seasonal or permanent home in the region, there is additional “non-market” value in the form of the traveler's/homeowner's satisfaction from the experience. For most people and for most market transactions, there is a “consumer surplus” defined as what people *would* pay for a good, service, or experience over and above what they *do or have to pay* (that is, the market price) for it.

Our estimates do not include direct costs of monitoring and attempting to mitigate potential and actual damage to ecosystems that may occur over the course of opening, operating, and in a few short years, shutting down mining operations. The need to monitor for acid drainage and other impacts would continue for decades and centuries after operations have ceased and any benefits from sulfide-ore-mining are a distant memory. In the shorter term, erosion and sedimentation, health effects of dust and light pollution, and higher maintenance costs for roads and other infrastructure would entail expenditures by individuals and local governments as well as non-market impacts on human well-being.

Our estimates below do reflect a portion of such impacts. For example, if noise, dust, and light pollution or other insults to the ecosystem service value of land near mining sites reduces the value of a seasonal or year-round home, there would be a reduction in the market price (fewer dollars exchanged) if and when the home sells. Prior to sale, however, the current owners would experience a loss of well-being or satisfaction with their home that could be greater than the eventual loss in market value.

Finally, we have not attempted to estimate losses of what are known collectively as “passive-use value”. This is the value to people of keeping places like the Boundary Waters as clean, aesthetically

appealing, and ecologically intact as possible for the sake of potential future use by oneself (“option value”) or by one’s descendants (“bequest value”). Passive-use value also includes “existence value”, which is the value to individuals of keeping places like the BWCAW intact to even if those individuals have no expectation of ever using or enjoying the place directly.

While effects on ecosystem services and drops in passive use value may be reflected in economic measures of the effects we explore below, we do not contend that we have captured the full costs, either market or non-market, of those effects. The major caveat to these estimates, therefore, is that what we “see” or estimate here may be but the tip of a very large iceberg of economic costs that are not as readily apparent, at least not yet.

What Drives Costs of Sulfide-Ore Copper Mining?

Before getting to dollar estimates of the costs of sulfide-ore mining, we must consider what may drive the decisions to come to (or not) the region to visit, to live, or to start a business or, for those who had made such decisions in the past, whether to come back to or stay in the Arrowhead region or elsewhere in Minnesota. As noted above, the Forest Service should undertake a thorough examination of the extent to which sulfide-ore copper mining would affect such decisions. As a first step in that direction, we have considered and developed several indicators of what motivates such decisions and how strong the impacts of new mining activity in the watershed of the BWCAW might be.

Many local residents have stated that the effects of sulfide-ore copper mining operations on the community and natural environment--noise, dust, truck traffic, pollution of existing high-quality ground and surface water (which supplies drinking water to many local residents), risk of damage to fisheries and aquatic habitat--would likely result in fewer visitors to the region, discourage new businesses from locating, and deter new residents. “If there were mines in the Boundary Waters, it would change the reputation of the Boundary Waters as a whole, and damage businesses” asserts Bill Hansen, an owner of Sawbill Outfitters located between Ely and Gunflint (B. Hansen, personal communication, 2016). He continued, “once a mine has been built, it is really hard to develop new businesses near it.” Steve Piragis, owner of Piragis Northwoods Company in Ely, noted that just the perception of a sulfide-ore copper mining industrial zone on the edge of town would be enough to scare off people who might visit, or build a vacation home or otherwise settle in Ely (S. Piragis, personal communication, 2016). And the owner of Hungry Jack Outfitters (on the eastern side of the BWCAW), Dave Seaton, said he feels that there would be enough impact from the mine to damage outfitting (D. Seaton, personal communication, 2016).

In addition, residents believe the existence of sulfide-ore copper mining in the region would cause some of the current residents and businesses to leave the region (see Figures 14a and 14b, below). As the area becomes (perceived to be) less desirable, the value of remaining businesses, as well as the value of both year-round and vacation properties and related property tax receipts, all are expected to decline. Dave Seaton, for one, expressed concern about land and business values if the mine comes in, because he intends to sell Hungry Jack Outfitting at some point (D. Seaton, personal communication, 2016). Sulfide-ore copper mining would, he believes, take away from the value of the business to any prospective owner and therefore reduce the prices he might be offered.

Loving or Leaving the Boundary Waters Region

Figure 14a. Loving: Why do you choose to live or own land in the four townships area?

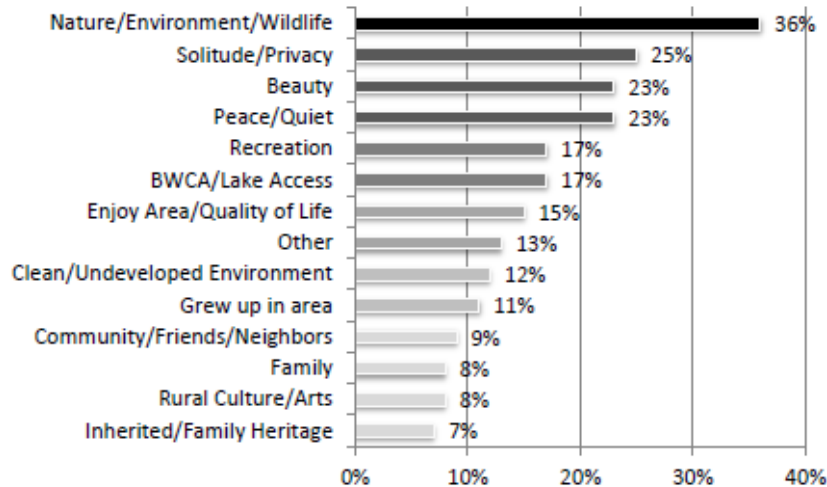
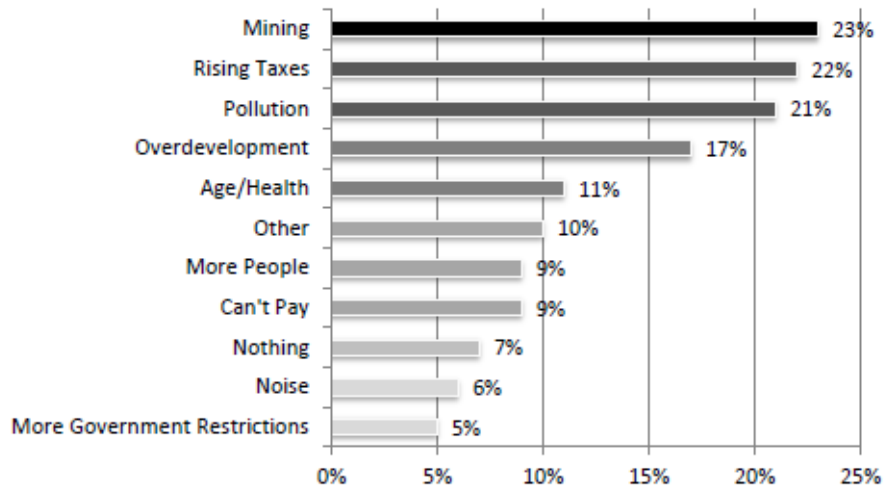


Figure 14b. Leaving: What factors would make you leave the four townships?



Source: Ronnader, R., Wentz, J., and Hove, M. (2014). *The Four Townships Area Economic, Housing Development Survey* (p. 51). Center for Small Towns and Data Services Center, University of Minnesota at Morris.

As part of *The Four Townships Area Economic, Housing and Development Survey*, researchers at the University of Minnesota, Morris asked property owners (both year-round and seasonal residents) about their reasons for owning property and/or living⁴ where they do and what might cause them to leave (Ronnader, Wentz, and Hove, 2014). The top reasons people gave for their having chosen to live

⁴ Some of the study's survey respondents owned property in the region, but do not reside there personally.

or own land in the region include “Nature”, “Beauty”, “Recreation”, “Undeveloped Environment”, and “Quality of Life” (see Figure 14a). Not surprisingly then, threats to or the loss of those amenities are among the top reasons people would leave the region. The most common reason, cited by 23% of respondents, was “Mining” (see Figure 14b). The researchers note that “a few” respondents indicated that their concern was that there are not enough mining jobs, but that mining was mentioned “mostly [by] respondents expressing [concern over] potential negative consequences from mining” (Ronnader, Wentz, and Hove, 2014, p.48). The next most common reasons, each cited by more than one in five respondents, why owners and residents would leave are “Rising Taxes”, “Pollution”, and “Overdevelopment”.

Survey of Arrowhead and Minnesota Business Owners

While the “four townships” survey described above touches on the question of whether and how sulfide-ore copper mining would affect residents’ and property owners’ decisions about whether to stay in the immediate region, there has not yet been a systematic survey conducted to discern the likely effects of sulfide-ore copper mining on the outlook of businesses in Minnesota.

To be sure, businesses have spoken out both for and against this new type of mining, and anecdotal evidence from letters to the editor, statements made at public meetings, and in other venues and documents (Northeastern Minnesotans for Wilderness, 2016) do suggest that for some businesses the advent of sulfide-ore copper mining in the Boundary Waters watershed would be catastrophic. But such data may not be readily generalizable to the whole of the economy or even to the portions that one would consider to be most directly affected by the proposed new mining industry. We therefore recommend that the Forest Service should conduct, as part of its withdrawal study, a thorough, statistically robust poll of business owners, residents, visitors, and others who have a stake in or who may hold values related to the quality of life and the quality of the environment in the watershed of the Boundary Waters.

In the meantime, we have attempted to obtain and use more systematic information as part of our estimates of potential costs presented below. Specifically, we used information from three sources:

1. Personal interviews with a group of small- and medium-sized retail, recreation, and tourism business owners from Ely and Grand Marais.
2. Review of 27 sworn affidavits filed in *Franconia Minerals (US) LLC; and Twin Metals Minnesota LLC, v. United States of America*: U.S. Department of the Interior; et al. (U.S. District Court, District of Minnesota).
3. Brief, anonymous, but nonrandom survey of business owners throughout the Arrowhead region and the whole of Minnesota. The survey was sent to 140 members of the “Boundary Waters Business Coalition,” and we received 31 responses for a response rate of 22%.

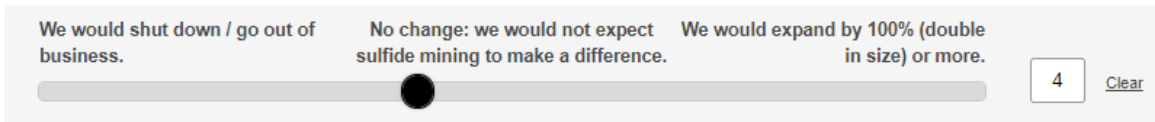
The business survey covered some basic information about each business (industry classification, size, etc.) as well as two key questions about each business owner’s (or, in some cases, a manager’s) realistic expectations for the future of their business in two scenarios: one with sulfide-ore copper mining in the watershed of the Boundary Waters, and one without. For these two questions, respondents moved a slider left or right from a “status quo” position. (See Figure 15 and Appendix A). The left and right ends of the scales represent extremes of “we expect to shut down” on the left, to “we expect to double or more” on the right. The position of the slider was automatically translated into a numerical score of zero to ten, and from this we infer a percentage change from the status quo in each scenario.

Figure 15: Survey Questions re: Business Outlook with and without Sulfide-Ore Mining in the watershed of the Boundary Waters

7. Scenario 1: If sulfide-ore mining is **NOT APPROVED** and the economy of the Arrowhead region (St. Louis, Lake and Cook Counties) continues to develop as it has over the past 30 years, what are your expectations for how **YOUR OWN** business/organization/agency might change over the next 5-10 years? 



8. Scenario 2: If sulfide-ore copper mining **WERE TO BE APPROVED** in the watershed of the Boundary Waters, how would you expect **YOUR OWN** business/organization/agency to change over the next 5-10 years? 



Note: The slider position and resulting numerical score (in the box to the right of each slider) show the average for the 31 responses received. We interpret the 7 in Scenario 1 (question 7), which is two steps above “No change” toward “...expand by 100%” to be interpretable as a 40% increase. Similarly, for Scenario 2 (question 8), the 4, which is one step (out of 5) toward “We would shut down...” to be interpretable as a 20% decrease.

Please see Appendix A for the complete survey.

From the survey responses we find that, on average, the businesses expected to grow by 40% over the next 5-10 years in a without-sulfide-ore copper mining scenario. In the with-sulfide-ore-copper-mining scenario, an average reduction in business of 20% over the same period is expected. We use this 20% reduction as the basis for estimates below of the effect of the proposed sulfide-ore copper mining industry on visitor spending, visitation, jobs, and income. Such a change does not seem unreasonable, given that traveler spending in Minnesota has increased by more than 20% in the past five years preceding 2016 (Tourism Economics, 2016)

This survey and the resulting estimates do have two countervailing caveats to keep in mind.

- First, a survey of business owners who have signed up as part of a coalition raising concerns about the mining proposal are more likely to be well-informed about the issue. Indeed, the respondents, on average, rated their awareness and knowledge of the issue as an eight on a zero to ten scale. To the extent that joining the coalition and being more informed on the issue correlates to opposition to the mining proposal, we would concede that the survey results are “biased” in the technical/statistical sense (i.e., we are not casting aspersions on the respondents), and we urge the U.S. Forest Service to conduct a random, statistically unbiased survey to get additional information about business owners’ and others’ expectations.
- Second, survey respondents do come from a range of industries (construction, manufacturing, retail, professional services, as well as recreation/tourism industries including lodging,

restaurants, guiding and outfitting). The respondents also do business from locations throughout the state. (The survey was anonymous, but we have information on industry category from a specific question, and we know something of the businesses' locations based on what some respondents volunteered in open-ended survey questions (see Appendix A). (As one might expect, businesses geographically closer to the Boundary Waters indicated that mining would have a stronger negative effect on their outlook than businesses down state.)

The fact that our cost estimates apply the statewide average to Arrowhead Region outcomes mitigates, at least partially, any sampling bias that may have colored the results. Moreover, we asked the business owners about their realistic expectations regarding the future of their businesses, not for their personal opinions. Interestingly, the lowest score on the question about expectations in the "with-sulfide-ore copper mining" scenario was a two (corresponding to a 60% reduction in the business). None of the respondents, in other words, indicated that they would go out of business completely. (Such expectations do show up in anecdotal information.) One business out of the 31 respondents, a small "retail/food & beverage" business, expects to double or more with or without the mine, even though they noted that sulfide-ore copper mining would hurt their sales and induce a change in focus toward other regions. That was an outlier, however: every other business indicated that it would either stay the same (8 businesses) or become smaller (23 businesses) in the "with-mining" scenario.

Estimated Costs: Three Ways Sulfide-Ore Copper Mining Would Affect the Arrowhead Region's Economy

There are at least three interrelated ways in which sulfide-ore copper mining would likely affect the economy of the Arrowhead region and, by extension, the entire state of Minnesota.

1. *Fewer visitors and less visitor spending:* The actual and perceived loss of environmental quality, including diminished quality of recreational experiences, would reduce the number of visitors coming to the region each year. That would translate into less spending, fewer jobs in all of the industries supported by visitor spending, and lower state and local tax revenues.
2. *Fewer in-migrants and more out-migrants:* The same effects on environmental quality would make the region less attractive to retirees, footloose entrepreneurs, mobile workers, or anyone else looking to reside or do business in a location with a high quality of life based on environmental factors and easy access to diverse, high quality outdoor activities (Florida 2000). As the "supply side" model of regional economic development suggests (see "Beyond Folk Economics", page 2), losing that quality of life will mean fewer in-migrants, more out-migrants, and as a result, less economic activity in all sectors.
3. *Loss of residential and commercial property values:* The value of being close to areas with outstanding natural amenities and opportunities for outdoor recreation is typically capitalized into nearby land values. As sulfide-ore copper mining reduces the amenities whose value is bound up with the overall value of residential and business properties, property value will fall, taking wealth away from current owners, and reducing local property tax revenue for years to come.

We consider each of these effects in turn.

Lost Visitor Expenditures

During a 12-month study period spanning 2007 to 2008, visitors (defined as persons staying one night or more in a location than 50 miles from their home) spent more than \$1 billion in the Arrowhead region (see Table 1, below) (Davidson-Peterson Associates, 2008). The study found that St. Louis, Cook, and Lake Counties ranked 3rd, 13th, and 16th, respectively, among Minnesota's 87 counties in terms of visitor spending. The study also broke down the direct impacts of that spending into its impacts in the regional economy. For each \$1 million in visitor spending, there were

- 16 direct jobs supported,
- \$264,666 in residents' income,
- \$106,770 in State (\$83,418) and local (\$23,352) tax revenue, and
- \$628,564 in proprietors' income and business-to-business spending

Note that these are direct impacts only and do not include "multiplier effects" that are calculated using input-output models. In this case, multiplier effects would comprise "indirect effects", which is spending by the businesses with whom the direct businesses (that is, those where the visitors spent their money) do business. Multipliers would also include "induced" effects that occur when people spend their earnings from work at businesses directly serving visitors or from work at the "indirect" businesses.

Davidson-Peterson Associates (2008) estimated total effects and found that multipliers in the Arrowhead region were 1.34 for jobs and 1.54 for residents' income and taxes. Thus, for every 3 jobs directly supported by visitor spending (in a hotel, at an outfitter, at a gas station, etc.) a fourth job would be supported in another business (for example, the outfitter's accountant, or the gas station's parts supplier). Similarly, for every two dollars spent by visitors, a third dollar would be spent in the Arrowhead economy, as the hotel manager, the outfitter's accountant, etc., spend their paychecks in the community.

Table 1. Estimated Direct Economic Impacts of Traveler Expenditures, 2008 & 2015, and Annual Losses with Sulfide-Ore Copper mining.

	Spending & Impacts, 2008	Impact per \$1 million Spending	Projected Spending & Impacts, 2015 (in 2016\$)	Losses with Mining (2016\$ & Jobs)
Traveler Expenditures	\$ 1,024,726,048	n/a	\$ 1,438,413,258	\$ 287,682,652
Jobs (full-time equivalent)	15,787	16	22,448	4,490
Resident Income	\$ 271,210,252	\$ 264,666	\$ 380,699,234	\$ 76,139,847
State Revenue	\$ 85,480,425	\$ 83,418	\$ 119,989,315	\$ 23,997,863
Local Revenue	\$ 23,929,452	\$ 23,352	\$ 33,589,895	\$ 6,717,979
Proprietors Income + Business-to-Businesses	\$ 644,105,920	\$ 628,564	\$ 904,134,814	\$ 180,826,963

Source: Davidson-Peterson Associates (2008), adjusted using trend data from Tourism Economics (2016).

To bring the estimates of direct visitor spending closer to the present, we turn to a recent study by Tourism Economics (2016) that tracked statewide visitor spending from 2009 through 2015. The average annual growth rate in that spending was 5.0% (range: 3.1% to 7.8%). We applied that growth rate to the Arrowhead expenditure estimate for 2008 and, applying each year's statewide growth rate,⁵ we estimate that visitor spending in the Arrowhead region reached \$1.44 billion by 2015 (in 2016 dollars) (Table 1). That 2015 spending would have supported:

- 22,448 direct jobs
- \$380.7 million in residents' income
- \$153.6 million in state (\$120.0 million) and local (\$33.6 million) taxes
- \$904.1 million in proprietors' income and business-to-business sales.

Finally, with our survey of business owners as a guide, we consider what the impact of a 20% reduction in visitor spending would mean for the Arrowhead region. Losing that \$287.7 million in spending would cost the region 4,490 jobs (about 4.9% of total private employment in the region), \$76.1 million in workers' income, \$30.7 million in state and local taxes, and \$180.8 million in proprietor's income and business-to-business sales (Table 1). That loss would occur each year that the presence and operation of sulfide-ore copper mining keeps 20% of visitors away.

Because Davidson-Peterson collected and reported data from visitors based on where they stayed (travelers were surveyed on-site during their visit), it is likely that their initial spending estimates reflect spending throughout Minnesota even though that spending is ascribed to the county where the traveler was staying when surveyed. Thus, a traveler who lodges in Ely before jumping off for a canoe trip in the Boundary Waters Canoe Area Wilderness would have been asked about all their spending to get there, what they planned to spend on provision, guiding services, what was paid for a meal at a restaurant on the way to Ely, and the cost of gas for a rental car. The entire expense of the trip would have been tagged as being due to the time in St. Louis County. By the same token, if our traveler had been surveyed during a one-night stay in a Minneapolis hotel before flying home, all those expenses would have been ascribed to Hennepin County.

This feature of the underlying data means that some travelers' expenditures are misplaced, but we assume that for any given county, the misplacement of expenditures goes both ways: some dollars are ascribed to the county that should not be, and other dollars that were spent in the county were ascribed to another county. We assume that in aggregate, these errors cancel each other out. We therefore have not attempted to estimate the portion of expenditures occurring in the Twin Cities or elsewhere in Minnesota that are, in reality, due to the attraction of the Boundary Waters.

Losses to the Broader Economy

Amenity-rich communities around the country know that a high quality of life, including a clean environment and access to high-quality outdoor recreational and scenic resources, are the natural capital that supports much of their economies. Visitation and visitor spending are certainly part of that, but the effect extends to all sectors of the economy. This is especially true for "footloose industries" or operations that do not need to be located near either input supplies (e.g., commodity raw materials),

⁵ For 2008-2009, for which calculation of a statewide annual growth rate was not possible, we used the average of the growth rates for 2009 through 2015.

or output markets. With today's global economy, and advanced communication and transportation networks, the list of industries that are footloose grows by the year.

For example, Niemi and Whitelaw (1999) state: "natural-resource amenities exert an influence on the location, structure, and rate of economic growth.... This influence occurs through the so-called people-first-then-jobs mechanism, in which households move to (or stay in) an area because they want to live there, thereby triggering the development of businesses seeking to take advantage of the households' labor supply and consumptive demand" (p. 54). They note that decisions affecting the supply of amenities "have ripple effects throughout local and regional economies" (p. 54). Similarly, Johnson and Rasker (1995) found that quality of life is important to business owners deciding where to locate a new facility or enterprise and whether to stay in a location already chosen. This is not surprising. Business owners value safety, scenery, recreational opportunities, and quality of life factors as much as residents, vacationers, and retirees.

As we have already seen (Ronnader, Wenthe, and Hove, 2014), environmental quality, recreational opportunities and other quality of life factors are the most important reasons Arrowhead residents give for living in and owning property in the region.

To the extent that sulfide-ore copper mining would diminish the physical qualities of the natural environment in the Arrowhead region, or even to the extent mining would alter the perception of those qualities--that is if mining damaged the region's "brand" built on the quality of the environment--one would expect that fewer people will want to relocate to the region to retire, to take a job, or to start up a new business. The "four townships" study and our business survey gives some information about the potential magnitude of that effect, and we use that information to sketch a set of simple scenarios for what the impact on jobs and income might be. We do note up front, however, that further research to determine more precisely how mining might affect location decisions by current and potential residents would be desirable as part of the review of mining in the Boundary Waters watershed.

Ronnader, Wenthe, and Hove (2014) found that 23% of property owners said that concerns over mining would cause them to leave, or at least want to leave, the region. Similarly, our survey of business owners indicates that sulfide-ore copper mining could depress their businesses' prospects by 20%, on average. One scenario, therefore, would be that there is a 20% drop in economic activity in the region.

As a general indicator of economic activity, we begin with total employment and total personal income. Both include proprietors' (the self-employed) additions to the economy. Total personal income also reflects the contribution of retirees in that it includes income from investments and transfer payments like Social Security and Medicare that retirees would spend in the region.

To avoid double counting, we then net out the contributions to jobs and income from visitor spending. We also net out those jobs and income in industries least likely to be footloose, namely farming, forestry, and mining itself.

We also consider two less drastic scenarios. In a second scenario, we consider the effect of a 10% drop in jobs and income, and in the third, we consider no actual drop, but merely a cessation of the growth the region has seen since the beginning of recovery from the mining bust of the early 1980s. Since 1983, the Arrowhead region has seen average annual job growth of 4.4% and average annual growth in total personal income of 5.0%.

The range of impacts from these scenarios range from a loss of 5,066 jobs and \$402.4 million in personal income (per year) if growth simply flatlines, to a loss of 22,791 jobs and \$1.6 billion in annual income if 20% of the economy were to, essentially, move away. See Table 2 for details.

Table 2: Overall Economic Decline in Three Scenarios for the Impact of Sulfide-Ore Copper Mining

	Jobs	Income (000s of 2016\$)
Total Jobs or Personal Income	134,402	\$ 9,400,027
Less Travel-Related	15,787	\$ 903,570
Less Commodity-Related	4,660	\$ 464,755
Potentially Amenity-related	113,955	\$ 8,031,702
Mining Impact Scenarios		
20% reduction	-22,791	-\$ 1,606,340
10% reduction	-11,396	-\$ 803,170
No Growth*	-5,066	-\$ 402,369
* Loss of 4.5% job growth, and loss of 5.0% income growth Sources: Headwaters Economics: Economic Profile System- https://headwaterseconomics.org/ ; SocioEconomic Measures: Underlying Data Sources: U.S. Department of Commerce. 2016. Bureau of Economic Analysis, Regional Economic Accounts, Washington, D.C. Tables CA30, CA05N, and CA25N; Ronnader, Wente, and Hove (2014); and tourism data cited above.		

Lost Property Value

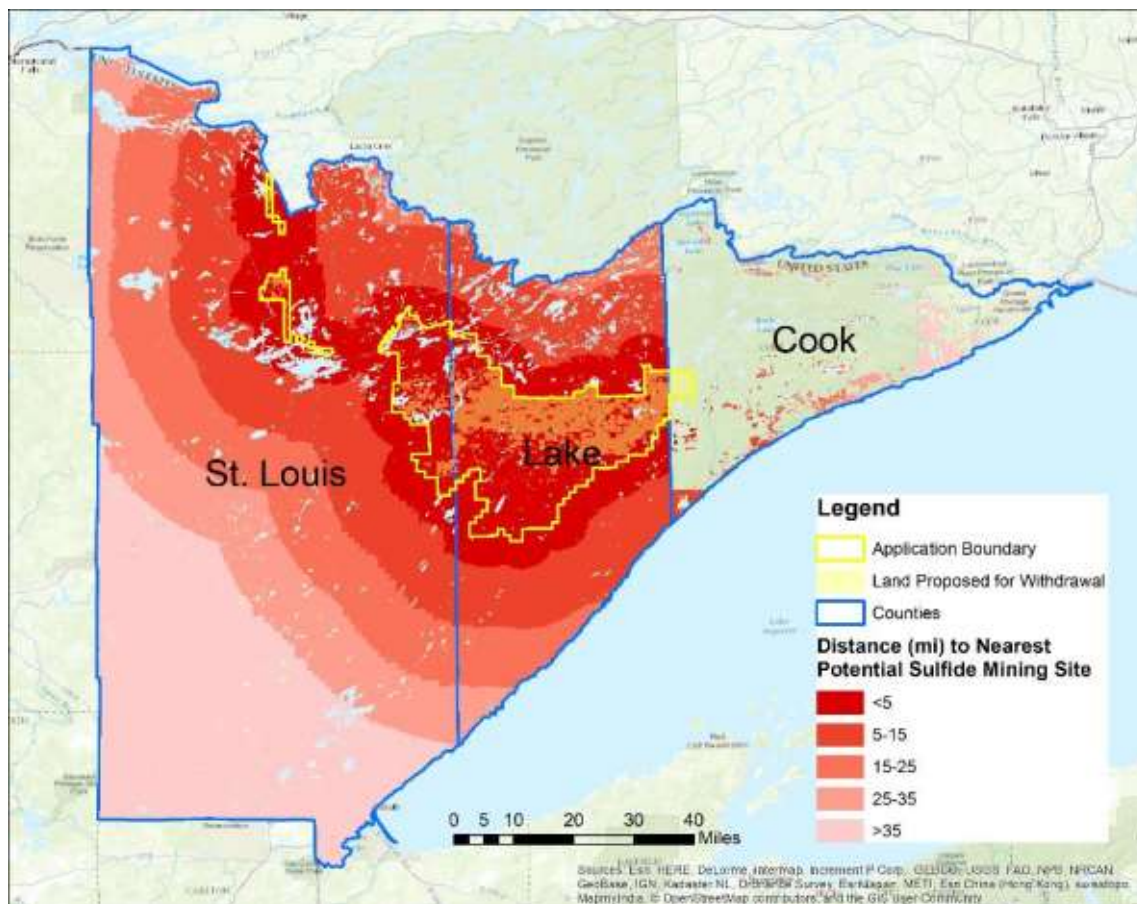
There is a ring of truth to the old saw that “location, location, and location” are the three things that matter most to the value of real estate. Namely, the location of a property relative to various amenities and disamenities can have a significant impact on buyers’ willingness to pay for the property. Natural amenities, like clear lakes (Schuetz, Boyle, and Bouchard, 2001), pastoral scenery (Fleischer and Tsur 2009), and wilderness and other protected areas (Phillips 2000; Beaton 1991) add value to properties over and above other attributes (improvements, road frontage, school quality, tax rates, etc.) that also influence land prices.

The same is true of disamenities: there are negative impacts on land value from various types of local nuisances that impose noise, light, air, and water pollution, life safety risks, and lesser human health effects risks on nearby residents and even entire communities that “gain” a new industry with such impacts (Sun, 2013; Bolton and Sick, 1999; Boxall et al., 2005; Williamson, Thurston, and Heberling, 2008). Erickcek (2006), Sun (2013), and Kim and Harris (1996) studied gravel, gold, and copper mines, respectively, and found that, in general, the closer a property is to the mine site, the lower is its property value. This negative effect typically decays with distance--that is, moving another mile closer to the mine produces a bigger drop in property value if you are already closer to the mine. In Sun’s study, which covered a time span that included both the opening and the closing of the mine, also found a large negative impact on every property in the county that occurred when the mine opened.

For this study, we apply the parameters from Kim and Harris (1996), who examined property values near a copper mine in Green Valley Arizona. To take the decay in the effect of the mine into account, they used a nonlinear transformation of distance to the mine in place of the simple distance. (The transformation is $X=1.05-(0.9947)^D$, where “D” is the distance in miles from the subject properties to the mine.) As is typical in these studies and for statistical reasons, the authors used a “log-log” version of the model in which the natural logarithm of the price of property is regressed against the natural log of the transformed distance and other variables. The coefficient on the distance function (0.2872 in their case) then represents the change, in percentage terms, of a property “moving” one percent farther away from the mine, when other things are held equal.

We do not have full information about all attributes of the properties in the Arrowhead region, but by computing distances from each property to potential sulfide-ore copper mining sites and applying the coefficient on the transformed distance, we can derive an estimate of the impact of new mining activity on properties in the Arrowhead. We conducted the analysis based on the distance from each property to the nearest Forest Service fee-owned parcel within the “Application Boundary”. In other words, we computed the distance from each private parcel to the nearest point that could, if the 20-year withdrawal is not approved, be subject to sulfide-ore copper mining. (See Figure 16).

Figure 16: Parcel Distance to Areas Potentially Open to Sulfide-Ore Copper Mining



Sources: St. Louis, Lake and Cook Counties’ respective GIS and Tax Offices, USDA Forest Service, ESRI.

We obtained parcel maps and information on the value of each parcel directly from each of the three Arrowhead counties. Due to the per-parcel fee charged for Cook County data, we obtained data only for privately owned parcels. Because publicly owned parcels do not have listed values and are not subject to sale, they should suffer no loss in market value due to mining. This gap in the data does not affect the analysis, but it is something to keep in mind when viewing the map in Figure 16. Publicly owned parcels in Lake and St. Louis Counties also have no market value, but the data sets for those counties did include all parcel boundaries.

Using the “NN Join” plugin in Quantum GIS, we calculated the distance from each parcel to the nearest polygon representing an area potentially open to sulfide-ore copper mining. The greatest potential separation is 77.9 miles to a parcel in northwest St. Louis County.

After computing these distances, and we then applied the statistical results from Kim and Harris (1996) to estimate the percentage change in property value (which is how one interprets those results when the log-log functional form is used). Parcels closest to mining sites would lose 5.74% of their value, and those farthest away would lose as little as 0.66%. By applying these percentages to each of the more than 243,000 parcels, per-parcel losses and aggregate property value losses are obtained.

Based on these procedures, we estimate that some \$508.9 million in property value would be lost if sulfide-ore copper mining were to occur on all of the areas proposed for withdrawal from the federal mining program. (See Table 3.)

Table 3. Estimated Property Value Impacts of Sulfide-Ore Copper Mining, 2016.

	Number of parcels	Total Property Value (2016\$)	Property Value Lost (2016\$)
Cook County	8,460	\$ 1,651,043,600	\$ 30,722,257
Lake County	45,303	\$ 3,378,180,900	\$ 115,161,294
St. Louis County	182,143	\$ 20,760,741,439	\$ 363,031,214
Total	235,906	\$ 25,789,965,939	\$ 508,914,765

As with other costs discussed in this report, we believe the actual impacts of sulfide-ore copper mining on land value would be much higher than those presented in Table 3. There are two primary reasons actual effects would be higher.

First, the study from which we used parameter estimates was focused on air quality impacts of copper mining that, while acute for properties closest to the mine, could decay more rapidly as distance from the mine increases. For other facets of the value of land in the Arrowhead region, such a decay may not be as pronounced, or it may not occur at all. For example, one may own (or consider buying) property in the Arrowhead region so that one can be relatively close to high quality recreational resources or to places with high levels of wilderness character.

The ability to get to high quality recreational resources and relatively pristine natural areas is reflected in buyers’ willingness to pay for properties near such resources and is capitalized into the price of properties throughout the Arrowhead region and, arguably, throughout the entire state of Minnesota. When noise, light, dust, and water pollution due to sulfide-ore copper mining diminishes the quality of the experience of areas near mining sites--or even if it diminishes only the *perception* of the quality of the experience--people will likely be willing to pay less for first or second homes purchased with an eye

toward be near the Boundary Waters. In other words, impacts on property values may remain strong over much greater distances than our conservative assumptions and these initial estimates suggest.

The other reason these property value effects are low is that they are merely “partial equilibrium” effects. They capture (at least some of) the direct nuisance effect of mining on property values, but they do not capture the second-round effects of a loss of vitality in the economy due to reductions in visitor spending and lost overall economic vitality. If population, jobs, and income decrease due to the advent of sulfide-ore copper mining, as described in the preceding sections, there will be fewer people with fewer dollars and with less optimism for a future, sustainable economy. Demand for housing will suffer along with the rest of the economy, and housing prices can be expected to fall. That may be good news for someone moving to the Arrowhead to take one of the comparative handful of new mining jobs, but for property owners already invested in the region, it will mean a loss of asset value and personal wealth.

SUMMARY AND RECOMMENDATIONS TO THE FOREST SERVICE

The Arrowhead Economy benefits from unique scenic, recreational, and environmental amenities. The clean water, peace and quiet, canoeing and hiking trails of the Boundary Waters Canoe Area Wilderness and the surrounding Superior National Forest, Voyageurs National Park, and the North Shore of Lake Superior are well-known international attractions for visitors and for new residents. In order to protect these outstanding resources “from the potential adverse environmental impacts arising from exploration and development [of mineral resources on federal lands]”, the Forest Service has proposed withdrawing 234,328 acres of federally owned land in the Rainy River watershed from the federal mining program (82 FR 4283).

The Forest Service is now scoping its Environmental Impact Analysis, which under the National Environmental Policy Act, must consider the economic effects of the proposed action alongside ecological, aesthetic, historical, social, and health effects (40 CFR 1508.8). The salient economic effects of this action would include, as a benefit to society, the avoidance of costs associated with actual and potential sulfide-ore copper mining that, absent the proposed action, could proceed in the watershed of the Boundary Waters. As the estimates described here demonstrate, even a fraction of those costs significant. The small subset of potential economic effects of sulfide-ore copper mining considered in this report include

- A decline in spending as potential visitors choose alternative destinations with high quality scenic and recreational amenities undiminished by nearby mining activity. We estimate an annual loss of \$288 million in spending that would otherwise support 4,490 local jobs, \$76 million in residents’ income, \$31 million in state and local taxes, and \$181 million in proprietor's income and business-to-business transactions
- 5,066 to 22,791 lost jobs, and between \$402 million and \$1.6 billion in lost annual income in the rest of the economy if sulfide-ore copper mining suppresses or reverses growth in the amenity-based economy that has been the backbone of the region’s recovery since the early 1980s
- \$509 million in lost property value. This is a one-time drop in asset value that will spawn annual reductions in local property tax revenue throughout the Arrowhead region.

As the caveats given along with our methods and estimates suggest, these numeric estimates should be considered conservative first approximations of the true and complete costs of sulfide-ore copper mining in the watershed of the Boundary Waters and, by the same token, of the positive economic effects of the proposed action). We would therefore recommend the Forest Service devote sufficient time and resources to fully explore all of the economic effects of the proposed action. Specifically, the agency should include the following in its Environmental Impact Assessment:

1. Conduct a systematic survey of business owners and managers to estimate the effect of potential sulfide-ore copper mining on the outlook for Minnesota, and especially Arrowhead Region, businesses in all sectors.
2. Complete a thorough, statistically valid survey of residents, visitors, vacation and second homeowners, and other stakeholders to determine the sensitivity of individual's and other stakeholders' decisions about whether to vacation, retire, locate, or stay in the Arrowhead region under alternative scenarios involving the presence and extent of sulfide-ore copper mining in the proposed withdrawal area.
3. Commission or perform a hedonic price study of residential, commercial, and other property values in areas where similar mining operations have occurred. The scope of effects in such a study should go beyond direct air, water, and visual effect, to include effects on "wilderness character". Insights and parameters from such a study should then be used to estimate land value effects near the proposed withdrawal area.
4. Examine the extent to which forecasted mining employment in both lower- and higher-wage positions will be available to, and filled by, current Arrowhead residents. That is, how will the potential benefits of sulfide-ore copper mining be distributed among existing residents and workers brought in from elsewhere.
5. Evaluate the avoided impact on all ecosystem services that would occur if the proposed withdrawal is not implemented. Ecosystem services affected would include:
 - a. timber (a renewable raw material) from forestland is lost to mine-related infrastructure, including roads, buildings, tailings piles and others;
 - b. food, including the nutritional value of fish and game species and edible wild plants no longer able to use or thrive in terrestrial and aquatic habitat affected by mining;
 - c. water for drinking;
 - d. recreational opportunities, including as valued by impacts (expenditures, jobs, income, etc., as considered in this report) as well as by benefits (the value to the recreational user over and above the out-of-pocket cost of the recreational experience). Loss of benefit if the proposed withdrawal is not implemented would afflict would-be visitors who stay away due to the new type of mining in the Boundary Waters watershed, as well as those visitors who do come but find their experienced diminished by sulfide-ore copper mining; and
 - e. other ecosystem benefits described, for example by Balmford et al. (2010).
6. Estimate impacts on passive-use value. The Boundary Waters belong to and are loved by people throughout our Nation and the world who would want to know that its resources remain unimpaired and who would want to ensure that they or their descendants have the option of future use of the Boundary Waters without the impacts of sulfide-ore copper mining.

Above all, the Forest Service's economic analyses to be included in the Environmental Impact Statement should be grounded in a 21st-century understanding of economics and the reality that there is more to the foundation of the Arrowhead Region's economy than what can be dug up and shipped away.

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APPENDIX A: BUSINESS OUTLOOK SURVEY

Using Survey Monkey, we solicited input from 140 members of the “Boundary Waters Business Coalition”. We received 31 responses (a 22% response rate) to the following 10-question survey.

1. Which of the following best describes the industry that your business (or non-profit or public agency) is a part of?

[Options included all two-digit NAICS industries, plus some three-digit industries where the distinctions between, say, “Retail, clothing and accessories” and “Retail, food & beverages” could have been helpful.]

Industries describing the respondents businesses were:

Agriculture, forestry, fishing and hunting	(n=2)
Arts and entertainment (galleries, theaters, etc.)	(n=1)
Construction	(n=1)
Information (publishing, motion pictures, internet hosting and content)	(n=1)
Manufacturing, apparel	(n=1)
Manufacturing, Other	(n=1)
Manufacturing, wood Products	(n=1)
Other services	(n=1)
Professional, scientific, and technical services (law, accounting, etc. not health)	(n=1)
Recreation, guiding and outfitting	(n=7)
Retail, clothing and accessories	(n=1)
Retail, food & beverages	(n=2)
Retail, sporting goods (which may include clothing)	(n=7)
Other or Combination	(n=4)

2. Which of the following best describes your role in the business/organization/agency?

Owner/Co-owner	(n=26)
Senior Manager	(n=2)
Employee	(n=3)

3. How many FULL-TIME employees did the company have in 2016? (Include yourself if applicable.) Please count only those who worked full-time and year-round.

1-4	(n=19)
5-9	(n=3)
10-19	(n=6)
1,000 or more	(n=1)
No answer	(n=2)

4. How many PART-TIME employees did you have in 2016? (Include yourself if applicable.) Please count employees who worked less than full time AND those who worked any number of hours per week, but for less than the full year.

1-4	(n=10)
5-9	(n=7)
10-19	(n=6)
20-49	(n=2)
50-99	(n=1)

1,000 or more	(n=1)
No answer	(n=4)

5. Gross Sales: What was the level of your gross sales (or if an organization or agency, what was your budget) in 2016? Remember, your answers are confidential and will be used only as part of aggregate measures (averages, etc.).

Less than \$100,000	(n=6)
\$100,000 - \$500,000	(n=12)
\$500,000 - \$1 million	(n=5)
\$1 - \$5 million	(n=6)
More than \$100 million	(n=1)
No answer	(n=1)

6. How would you rate your awareness of/knowledge about the issue of sulfide-ore copper mining in the watershed of the Boundary Waters, and your level of engagement (talking about, writing letters, reading up on, etc.) related to the issue?

Average of 8 (range 5-10, n=31) on a 0-10 slider, where

0 corresponded to "I have not heard much or anything about it."

5 corresponded to "I am pretty well informed about the issue, but I am not actively following or taking any action related to it.", and

10 corresponded to "I know a lot about the issue, and I am regularly engaged in conversations and actions related to it."

7. Scenario 1: If sulfide-ore mining is NOT APPROVED and the economy of the Arrowhead region (St. Louis, Lake and Cook Counties) continues to develop as it has over the past 30 years, what are your expectations for how YOUR OWN business/organization/agency might change over the next 5-10 years?

Average of 7 (range 5-10, n=31) on a 0-10 slider, where

0 corresponded to "We expect to shut-down/ go out of business."

5 corresponded to "No change: we're about the right size.", and

10 corresponded to "We plan to expand by 100% (double in size) or more."

8. Scenario 2: If sulfide-ore copper mining WERE TO BE APPROVED in the watershed of the Boundary Waters, how would you expect YOUR OWN business/organization/agency to change over the next 5-10 years?

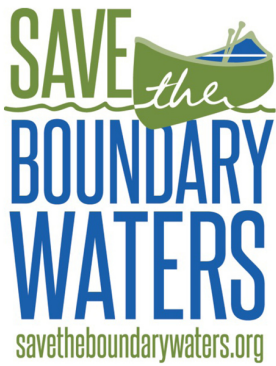
Average 4 (range 2-10, n=31) on a 0-10 slider, where

0 corresponded to "We expect to shut-down/ go out of business."

5 corresponded to "No change: we're about the right size.", and

10 corresponded to "We plan to expand by 100% (double in size) or more."

9. For the second scenario please describe HOW you would expect sulfide-ore mining in the watershed of the Boundary Waters to affect your outlook and your plans for your business or organization.
10. Please use this space for anything else you would like to say about the current and future business climate, economic development, or the prospects for your own business as it relates to sulfide-ore copper mining proposed for the watershed of the Boundary Waters.



Copper Mining in the BWCA Watershed: Minnesota's Arrowhead Region Has Far More to Lose Than Gain

A new study of the Arrowhead Region's economy reveals a diverse and growing economy in which numerous industries – including healthcare, tourism and recreation, small businesses, manufacturing, construction, services, forest products and taconite mining – can coexist peacefully **as long as copper mining does not occur in the Boundary Waters watershed.**

The report also details the formidable economic costs to the three-county Arrowhead Region that would follow the introduction of sulfide-ore copper mining within the Boundary Waters Watershed – including major losses in jobs, visitor spending, property value, Main Street businesses and more. Although taconite mining outside the watershed still accounts for 2.5 percent of the region's overall employment, the majority of economic activity supporting jobs in a wide range of industries now relies predominantly on a healthy, pristine Boundary Waters Wilderness to attract and retain business owners, workers, visitors and retirees.

The new study concludes that **opening the watershed to sulfide-ore copper mining would result in huge costs for businesses, workers and communities throughout the region by damaging the strongest growing elements of the existing Arrowhead economy.**

Since the mining decline of the 1980s, the Arrowhead has seen growth in key indicators:

- **Population:** Steady growth in population (after an early-1980s decline).
- **Income:** Steady growth in personal income across a diverse set of industries.
- **Small Business:** Growth in sole proprietors' employment and income.
- **Investment:** Increases in non-labor income, such as investments and Social Security.
- **Diversifying Economy:** These industries have experienced the strongest growth:
 - Professional services - up 12.3% (since 2010);
 - Real estate - up 12.1% (since 2010);
 - Educational services - up 10.0% (since 2010);
 - Arts, entertainment and recreation - up 8.9% (since 2010).

Based on conservative assumptions, sulfide-ore copper mining in the Boundary Waters watershed would cost the Arrowhead economy:

- **Travel & Tourism:** \$288 million in lost annual visitor spending that would support:
 - 4,490 local jobs;
 - \$76 million in residents' income;

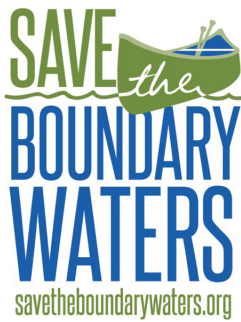


- \$31 million in state and local taxes, and
- \$181 million in proprietor's income and business-to-business transactions.
- **Diverse & Growing Industries:** 5,066 to 22,791 lost jobs and between \$402 million and \$1.6 billion in lost annual income if sulfide-ore copper mining suppresses or reverses overall amenity-based growth at the heart of the Arrowhead's recovery since the early 1980s.
- **Property Value:** \$344 million to \$509 million in lost property value – a one-time drop in asset value should sulfide-ore mining be allowed in the Boundary Waters watershed that will spawn annual reductions in local property tax revenue throughout the region.

The new report by Key-Log Economics, which totals 42 pages and examines and analyzes a wide range of economic data in St. Louis, Cook and Lake counties, can be found [here](#).

FOR MORE INFORMATION:

Visit SavetheBoundaryWaters.org or Facebook.com/SavetheBoundaryWaters



Twin Metals Minnesota Mine: A Case Study in the Economic Costs of Sulfide-Ore Copper Mining

... it is reasonable to assume that the opening of a [Twin Metals] mine could lead to the initial loss of anywhere from \$22.9 million to \$28.6 million in local income, a figure that would likely increase over time. Ely Timberjay news story 8/3/17

This is why the two-year federal study on the costs and benefits of a potential mine is so valuable, and why current efforts to short-circuit the study are ultimately risky, potentially even destructive, to Ely's economy. Residents of the area would benefit tremendously from the kind of thoughtful and informed exploration that the federal study could provide. We need to recognize that mining jobs represent only one side of the ledger. Anyone in business knows that you need both sides to make an informed decision. Ely Timberjay editorial 8/3/17

An economic analysis published by the Ely Timberjay on August 3, 2017 provides an in-depth look at some of the potential economic costs associated with a proposed sulfide-ore copper mine in the Ely area. This analysis is a case study of one specific mine proposal, the Twin Metals mine, and the economic impact it would have on income generated by local residents in the Ely area (Ely and four surrounding townships—Morse, Fall Lake, Eagles Nest, and Stony River).

The Timberjay study is not to be confused with a recent [report](#) by Key-Log Economics that looked at the effects of sulfide-ore copper mining in the larger watershed of the Boundary Waters Canoe Area Wilderness. The Key-Log report covered over 234,000 acres of federal lands in which there has been extensive prospecting by multiple mining companies, and extrapolated impacts in multiple economic sectors across the three-county (St. Louis, Lake, and Cook) Arrowhead Region that is home to the Boundary Waters. The stark findings of the Key-Log report show that sulfide-ore copper mining in the Boundary Waters watershed could cause the Arrowhead Region to lose up to \$288 million in annual visitor spending, 4,490 jobs in tourism, 22,791 jobs in the rest of the economy, \$1.6 billion in annual income, and \$509 million in property value.

Because the Timberjay study is limited to one potential mine and its impact on one community within the watershed it is not as comprehensive as the Key-Log Report. However, it provides a sobering look at what could happen to the Ely area if the Twin Metals sulfide-ore copper mine were developed. The full Timberjay analysis can be viewed [here](#), but among the important findings are:

- Majorities of both year-round and seasonal residents of the four townships view copper-nickel mining in the Ely area as a significant and negative development that could prompt a large

percentage to consider leaving the area. Based on a four-township survey by the University of Minnesota-Morris, 23 percent said that mining was the most important factor that would prompt them to leave the area.

- Collectively, permanent and seasonal residents of the four townships provide roughly six of every ten dollars of locally-based income available to generate economic activity in Ely.
- Collectively, the townships account for 82 percent of new housing construction activity in the Ely area. They provide an overwhelming amount of the real estate activity as well.
- Mining would likely have a negative impact on growth in recreational real estate purchases and housing unit construction in the townships. The low rate of housing construction in Stony River township from 2000-2010 was a period during which mineral exploration activity was intense in the township (Chart B, below). Proximity to mines negatively impacts property values.
- The full-time population of the townships is static, but the number of seasonal residents is growing in three of the four townships (Stony River being the exception). That trend provides income growth in the Ely area from annual construction wages and from spending by the additional seasonal residents.
- If 15 percent of township residents choose to leave the area or visit seasonal homes less frequently because of mining, it would lead to an initial loss of \$15.9 million in annual income to the Ely area economy. If 20 percent of township residents choose to leave or visit less frequently, the initial loss would be \$21.2 million. As the recent study led by economist Spencer Phillips noted, approximately 42 percent of residents of the region rely on investment income and transfer payments, such as Social Security, for their income, which leaves them much freer to leave an area if the attributes that currently keep them in the area are lost or impaired.
- The potential losses in local income would compound with time because of lost growth. From 2010-2015, according to census data, average income in Morse and Fall Lake Townships increased by 3.2 percent annually, which added approximately \$2.1 million per year in local income to the Ely area without accounting for the impact of new seasonal residents investing in, and spending time in, the townships. By contrast, incomes for Ely residents have remained static over the past five years, according to census data.

Finally, this analysis concludes:

Based on this analysis, it is reasonable to assume that the opening of a [Twin Metals] mine could lead to the initial loss of anywhere from \$22.9 million to \$28.6 million in local income, a figure that would likely increase over time.

This assumes losses based primarily on public perception of the loss of wilderness attributes in the Ely area. Significant documented environmental impacts, a major spill, or a catastrophic event, such as a tailings basin breach, could significantly increase the downside risks to the Ely area economy.

The data makes one critical point perfectly clear – the economic activity generated by the incomes of township residents and long-term investments in housing and other infrastructure,

is undoubtedly a major factor in Ely's economy. And keep in mind, our analysis looks primarily at the economic impact of income generated by local residents, whether year-round or seasonal. Economic activity generated by outside visitors, i.e. tourists, is an entirely separate issue.

Chart A
Average & total income of residents

<u>Twp./City</u>	<u>Avg. Income</u>	<u>Total Income</u>
Eagles Nest	\$60,000	\$7.5 million
Fall Lake	\$74,000	\$20.7 million
Morse	\$76,825	\$45.4 million
Stony River	\$47,500	<u>\$4.3 million</u>
Total income/ townships		\$77.9 million
Total income w/seasonal residents		\$106 million
 City of Ely	 \$45,800	 \$77.0 million

*Source: U.S. Census/ American Fact Finder
Does not include seasonal residents*

Chart B
New housing units 2000-2010

<u>Twp./City</u>	<u>Number</u>	<u>% increase</u>
Eagles Nest	131	37%
Fall Lake	134	17%
Morse	219	19.6%
Stony River	33	9.5%
Total units	517	20%
 City of Ely	 110	 5.7%

*Source: U.S. Census/ American Fact Finder
Includes both permanent and seasonal housing*

Chart C
Property values

<u>Twp./City</u>	
Eagles Nest	\$109 million
Fall Lake	\$345 million
Morse	\$414 million
Stony River	<u>\$ 88 million</u>
Total	\$956 million
 City of Ely	 \$164.5 million

Source: St. Louis County and Lake County Property Tax Records

the **TIMBERJAY**



(/)

Serving Northern St. Louis County, Minnesota

Township impact

In copper-nickel debate, we all should consider economic costs as well as gains

Posted Wednesday, August 2, 2017 6:19 pm

Anyone in business knows that a company's revenues account for only half of their financial equation. A business whose costs exceed its revenues is a business in trouble. The same calculus applies to local economies and must be considered as a community contemplates the implications of a major economic development project. Almost every development comes with direct costs, indirect costs, and potential risks. And every community should seek to understand those downsides as residents contemplate the wisdom of any project. Considering the benefits without weighing potential costs would be economic and political malpractice.

As the Ely area debates the merits of a copper-nickel mine, it is critical for residents and local political leaders to recognize that there are benefits, costs, and potential risks associated with any such proposal. We hope our story (see page 1), provides a starting point for discussion on that subject.

We used census data, election results, and academic studies, to better understand the differences in income levels, housing growth, and attitudes towards copper-nickel mining between residents of the city of Ely and residents of the outlying townships that factor heavily into Ely's economy. And we used those results to make estimates of the potential costs, in lost income, to the local economy.

A new mine would undoubtedly generate significant new income to the Ely area economy, mostly through the wages paid to mine workers. But if those gains are offset by income losses due to decisions to leave the area by some of the many residents of the townships who strongly oppose the opening of a sulfide mine in their watershed, the Ely area has assumed substantial environmental risk for little, if any, economic gain. Our analysis assumes that a dollar of income is worth the same to the local economy, whether it's spent by a copper-nickel miner or by a retiree who spends their pension and Social Security proceeds to live in the North Country.

Using this assumption, we looked at the data, made assumptions which we describe in our report, and offered reasonable conclusions. We recognize that the data could support other conclusions as well. Our report is hardly definitive, but is illustrative of the kind of calculations that should be undertaken,

preferably by actual economists hired by the Forest Service, before the area considers whether to support a potential copper-nickel mine. That said, we believe our report's conclusions are well-supported by the available data, and are likely conservative.

Our look at the data revealed some interesting trends. Most disturbing was the fact that Stony River Township has experienced relatively little new housing, either permanent or seasonal, since intensive mineral exploration by Twin Metals got underway in the township. That's in sharp contrast to other townships in the area. Whether that's a coincidence or evidence that mineral exploration and the potential for mining is limiting local investment isn't clear, but it's a question worth exploring. Would other townships, such as Fall Lake, located downstream of a possible mine, be avoided as well were a mine eventually built? A University of Minnesota survey of residents in the townships suggests the answer may well be yes.

The data makes one critical point perfectly clear— the economic activity generated by the incomes of township residents and long-term investments in housing and other infrastructure, is undoubtedly a major factor in Ely's economy. And keep in mind, our analysis looks primarily at the economic impact of income generated by local residents, whether year-round or seasonal. Economic activity generated by outside visitors, i.e. tourists, is an entirely separate issue.

This is why the two-year federal study on the costs and benefits of a potential mine is so valuable, and why current efforts to short-circuit the study are ultimately risky, potentially even destructive, to Ely's economy. Residents of the area would benefit tremendously from the kind of thoughtful and informed exploration that the federal study could provide. We need to recognize that mining jobs represent only one side of the economic equation in Ely. Without understanding the potential costs, we're considering only one side of the ledger. Anyone in business knows you need both sides to make an informed decision.



Comments

2 COMMENTS ON THIS STORY | [PLEASE LOG IN TO COMMENT BY CLICKING HERE \(/LOGIN.HTML\)](/LOGIN.HTML)

Steve Jacobson

I'll start on this one! As a business owner and miner from Ely I will tell you the absolute truth concerning my business "Ledger":

Summer = Good

Winter = Bad

Now, take those year round residents making an average of \$18k/year (from an earlier report) and replacing them with a thousand workers making \$80k/year. They will be building homes on the lakes and areas that you mentioned above. There is just no way a seasonal worker can do this, at least not out by a lake. I also do not believe the numbers of those leaving with their tales between their legs will be one tenth the number of new residents moving into the area with good paying jobs. I don't think we need two years to figure this out. This is just another delay tactic to get the lawyers lined up to delay it even further in the future.

Hardrockminer

Great post Steve! If it's not grown it's mined. We do it better than most of the rest of the world.

THURSDAY, AUGUST 3

OTHER ITEMS THAT MAY INTEREST YOU

'We're not paying to fix your streets' (/stories/were-not-paying-to-fix-your-streets,13796)

Duluth mayor gets an earful from Ely officials (/stories/duluth-mayor-gets-an-earful-from-ely-officials,13788)

Taconite taxes drop for third straight year (/stories/taconite-taxes-drop-for-third-straight-year,13797)

Study: Winter recreation faces challenge from climate change (/stories/study-winter-recreation-faces-challenge-from-climate-change,13794)



[ADVANCED SEARCH \(/SEARCH.HTML\)](/SEARCH.HTML)

A real estate advertisement for Janisch Realty. The top half features a scenic background of a lake and trees with a dog in the foreground. Text includes 'NEXT TIME COME HOME!®', 'JANISCH REALTY', 'lisajanisch.com', and '218-780-6644'. A photo of a woman is on the right. The bottom half has a blue background with a red box containing 'JANISCH REALTY' in white. Below that, it says 'Let's Make Sold Happen For You Too!' and provides the website and email address.

NEXT TIME COME HOME!®

JANISCH REALTY
lisajanisch.com
218-780-6644

**JANISCH
REALTY**

Let's Make Sold Happen For You Too!
www.lisajanisch.com • info@lisajanisch.com

(<http://timberjay.ads.communityq.com/www/delivery/ck.php?>

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Watch out, Ely: Mine robots are on the way

Are jobs obsolete? Automation in the industry is coming — and it's sooner than we think.

By Paul and Susan Schurke

OCTOBER 20, 2017 — 6:17PM

Antofagasta, the Chilean owner of the proposed Twin Metals copper mine near the Boundary Waters Canoe Area Wilderness, must take sly pleasure at the tedious backbiting and infighting here in Ely, Minn. It certainly diverts local attention from the tsunami that's hitting the mining workforce around the world.

"Taking the miner out of mining" is a major theme these days among mining industry planners, according to the article "The Robots Are Coming" in the current issue of Mining Magazine, a leading industry journal since 1909.

Industry news is abuzz with breakthroughs in automation and robotics. This is not pie-in-the-sky scheming: Four of Australia's open-pit iron mines, along with an underground mine, are already automated. Robotic excavators dig the ore, driverless trucks move it out of the mine, driverless locomotives take it to processing. Mining giant Rio Tinto, sensing the shock waves this might send through its global workforce, is quick to note that some of the miners have been retrained to monitor this equipment — at a robotics control facility in an urban center 750 miles from the mines. One operator can monitor an entire fleet of trucks that run 24/7 with no need for lunch or bathroom breaks and no risk of on-the-job injuries.

A key global planning study titled "Mining a Mirage?" by the Canada- and Switzerland-based Intergovernmental Forum on Mining concludes that automation is transforming the industry far faster than mining companies anticipated. And why wouldn't it, since automated mining is slated

to reduce operating costs by 50 percent and increase productivity by 30 percent? These efficiencies result largely from workforce reductions, which could be as large as 75 percent, according to references cited in the study.

When? The study notes that these technologies “are likely to reach their peak rates of deployment in the next 10 to 15 years.” That’s years before Twin Metals, even under its rosiest projections, anticipates having a shovel in the ground. By then, how many of the promised 850 mine-operator jobs will have been eliminated by automation?

In that same 10- to 15-year time frame, driverless trucks are expected to eliminate the nation’s most common job: our 3.5 million truckers. The driverless semi named “Otto” that transported 50,000 cans of beer across Colorado this summer might have been an Uber stunt — but it worked.

Minnesota’s Eighth District U.S. Rep. Rick Nolan, a Democrat who sits on the House Transportation and Infrastructure Committee, is well aware that the equipment-operator workforce is facing its demise within the next decade or two. But yet he panders for the vote of mining proponents while giving no hint that the jobs they hope for their children are rapidly destined for obsolescence — unless their kids want to monitor computers at a robotics control facility in an urban center hundreds of miles from Ely.

The “Mirage” planning study also concludes that, in socioeconomic terms, the traditional “social license” by which communities allow corporations to extract local resources in return for local jobs needs to be renegotiated — because the next generation of mines will offer few locals jobs. Here’s another opportunity for Nolan, or whoever replaces him, to exhibit some political leadership.

These sweeping automation trends mean that, with or without Twin Metals, mining employment will not be a significant factor in Ely’s workforce future. Every community in the country will need to reckon with this “mother of all” industrial revolutions. Fortunately, Ely is ahead of the curve with our downtown revitalization and burgeoning small-business movement.

References to our “amenities-based economy” may raise some eyebrows, but there’s no denying the fact that if we take care of our woods and water, Ely will always remain an appealing place to live, work and recreate. But its sustainability cannot rely upon the fading mirage of heavy-industry jobs.

Paul and Susan Schurke are owners of Wintergreen Northern Wear and Wintergreen Dogsled Lodge in Ely.

<http://www.startribune.com/watch-out-ely-mine-robots-are-on-the-way/451966383/>

Robots will run mines within the next decade, Anglo says

Published:

November 30 2017, 6:30am EST

(Bloomberg) -- Some mines in the next decade will run without humans and instead rely on robots, virtual models and sensors, according to Anglo American Plc.

Anglo is betting on technology, such as computerized drills with "chiseling ability as good as a human" to increase productivity, cut costs and reduce environmental impact, Tony O'Neill, technical director at Anglo, said at the Mines and Money conference in London.

"The industry that everybody currently knows will be unrecognizable" in five to seven years, O'Neill said. With mining processes automated, Anglo's "employee of the future" will only need to focus on managing the company's relations with governments and communities that live near its mines, he said.



Anglo operates some of the world's most valuable copper deposits and employs 87,000 workers from South Africa to Chile.

Bots, or software that can execute instructions, will be increasingly important in underground mining, O'Neill said. Small and self-learning, the technology requires less infrastructure than current methods, and commercial application is five to seven years away.

Anglo isn't the first to invest in automation. In Australia's Pilbara iron ore region, BHP Billiton Ltd. has begun work aimed at implementing autonomous trains along its 1,300-kilometer rail network. Barrick Gold Corp. is a year into the gold mining industry's most ambitious experiment to modernize digging, using thousands of sensors at and around the Cortez mine in Nevada.

Other technology uses real-time, virtual models of physical processes to prevent problems before they occur and can be deployed to monitor the mine, processing and distribution, O'Neill said. The systems, borrowed from the aerospace industry, could increase productivity by about 20 percent and lower costs by 15 percent, he said.

The company plans to use so-called "dry water" for cooling and other processes that use lots of liquid. It also aims to reduce mine waste, which would make tailings dams unnecessary.

<https://www.information-management.com/articles/robots-will-run-mines-within-the-next-decade-anglo-says>



State predicts PolyMet would need \$1B to cover risks from copper-nickel mine

Half would go for long-term water treatment after copper-nickel mine closes.

By [Josephine Marcotty](#) Star Tribune

DECEMBER 20, 2017 — 6:44AM



JIM MONE, ASSOCIATED PRESS The closed LTV Steel taconite plant sits idle near Hoyt Lakes, Minn. The site, which closed in 2001, may return to life as part of Minnesota's first copper-nickel mine, owned by PolyMet Mining Corp.

PolyMet Mining Corp. would have to put up roughly \$1 billion dollars halfway through the life of its proposed copper-nickel mine in northern Minnesota to protect state taxpayers from environmental

risks — with more than half the funds dedicated to a trust fund for water treatment that would be required long after the mine has closed.

The estimate by state regulators, obtained by the Star Tribune through a data practices request, for the first time puts a dollar amount on the significant risks to water, air and wildlife that come with a new kind of mining for Minnesota.

The peak-mining cost estimate is three times higher than what PolyMet first proposed a year ago, and approximates what outside engineering experts have recommended because of the scale and severity of potential water contamination from hard-rock mining.

The projections are contained in documents produced by state regulators as they develop financial protections that, by state law, must accompany [the permit to mine](#) that PolyMet is seeking. The permit will be open to public comment early next year, but officials say they haven't decided yet whether those long-term costs will be included.

The mining permit represents a critical turning point for one of the longest, most contentious environmental debates in state history.

Mining advocates see PolyMet's \$650 million open pit project near Hoyt Lakes, and others that are expected to follow, as the long-awaited economic rejuvenation of a once thriving mining community in northeast Minnesota. Environmentalists see it as a looming threat to the last remaining wild area of the state and the still-clean lakes and rivers that give Minnesota much of its identity.

Unlike taconite mining, copper-nickel mines can produce runoff that can generate acid that leaches hard metals and other contaminants from underlying rock, a problem that can linger for decades.

The mining industry and PolyMet officials say modern technologies and engineering can protect Minnesota's surface- and groundwater.

Still, some mining states, including Minnesota, require companies to post "financial assurance" in the form of bankruptcy-proof financial instruments that would pay for mine closure and environmental

cleanup if PolyMet or its successors should fail or walk away — as many mining companies have in other places.

The states' role in negotiating such protections became even more critical last week when Scott Pruitt, administrator of the U.S. Environmental Protection Agency, [dropped a new federal rule](#) that would have required mining companies to provide funds for cleanup.

Pruitt said it would impose an “undue burden on this important sector of the American economy.”

Even so, Minnesota regulators must now walk a careful line. If they ask too little in the way of financial assurance, residents, taxpayers, Indian tribes and Lake Superior — all downstream from the mine — could pay the price for any future environmental damage. If they ask too much, Gov. Mark Dayton and his administration could be blamed for thwarting the Iron Range's long-awaited economic boom.

Barbara Naramore, assistant commissioner for the Department of Natural Resources, said the state's primary goal is to “make sure taxpayers are adequately protected.”

She said the state is still crunching numbers, but has not moved much off the \$1.039 billion figure, detailed in agency documents, that could be needed to cover potential costs at the peak of production.

State law requires regulators to adjust the amount annually, based on the potential costs of closing the mine in each year of operation.

That means the initial costs are low, then rise over time as the mine gets larger, and then decline as site reclamation is completed.

Lasting challenges

Last week, PolyMet submitted a \$544 million financial assurance proposal for the first three years of construction and mining, but not beyond that.

The state, however, did. Using the company's financial and mining projections submitted as part of its permit applications, combined with additional data from outside consultants, it determined that after peaking in year 11, the potential cleanup costs would gradually decline to \$580 million in the 20th year. And that's where they would stay as the basis of a trust fund to pay for water treatment perhaps "in perpetuity."

PolyMet declined to comment on the state's numbers, but in an e-mailed response to questions, officials said that figuring out the amount annually is more accurate.

Others, however, commended the state for taking the long view.

"That's very realistic, based on what we know," said Ron Sternal, a former financial executive who is now a board member at the Minnesota Center for Environmental Advocacy.

He is among a handful of Minnesota business executives who publicly pushed regulators to set a high bar for PolyMet's financial assurance.

PolyMet's plan, according to the state's documents, would use bonds and irrevocable letters of credit for the first several years, but gradually replace them with cash from the mine's operations. But Sternal and other critics warned against relying on revenue because mining is so volatile.

"Financial assurance should not be, in any way, related or dependent on the economic viability of this thing," Sternal said.

Naramore said that if PolyMet is unable in any year to provide the necessary cash — or other financial instruments — the state can use its authority to withdraw the permit or curtail operations.

She agreed, however, that it would be politically difficult for the state to force the shutdown of a major business because of unpredictable environmental risks in the future.

Added Sternal: “The state has never shut down [a mine] because it’s not living up to its obligations,” referring to taconite mines that have operated for years without updated permits or meeting water quality standards.

“We think as citizens we should have full visibility and transparency as to what cash flows they think this mine will generate,” he said.

<http://www.startribune.com/state-predicts-polymet-would-need-1b-to-cover-risks-from-copper-nickel-mine/465327373/>



Ely's golden goose

Township residents power Ely-area economy

08/3/2017 By: Marshall Helmberger

<http://timberjay.com/stories/elys-golden-geese,13540>

Editor's Note: The following is an analysis of the potential economic risks associated with copper-nickel mining in the Ely area. It relies heavily on census data, county records, election results, and findings from a 2014 survey of residents in the townships surrounding Ely and looks primarily at income generated by local residents (whether permanent or seasonal), not outside visitors. It includes conclusions and assumptions which are presented within the narrative. We believe this is the best available data and that the assumptions are conservative. We hope this will add to the current debate over the wisdom of pursuing copper-nickel mining in the Ely area.

REGIONAL— An economic study released last month, commissioned by the Campaign to Save the Boundary Waters, suggests that thousands of jobs could be lost across the Arrowhead were a copper-nickel mine built on the edge of the canoe country.

As the Timberjay reported at the time, one potential weakness of the study is its assumption that the negative impacts that a mine would likely have on what it terms the “amenity-based” economy could be extrapolated across all of St. Louis, Lake, and Cook counties, including the city of Duluth. Using that approach, the study's authors estimated potential job losses that were extremely high, as many as 22,000 across the region and a loss of \$1.6 billion in annual income.

At the Timberjay, we see numbers that high as unrealistic, primarily because it is unreasonable to project similar economic impacts across the entire Arrowhead from mining in the Ely area. Residents in Duluth, for example, would see few of the new jobs created by a potential new mine, nor would they see many of the potential job and income losses that could come from diminishing the amenity-based economic model that continues to develop in the Ely area. We think both the positive and negative effects of such a mine would be concentrated in the Ely area. So, as residents in our region continue to debate the merits of Twin Metals' proposal, the Timberjay is offering new data to the discussion, gleaned almost exclusively from government and academic sources.

We've reported in the past on the job creation estimates associated with the proposed Twin Metals mine, with current company estimates of 650 permanent jobs, with an average salary of close to \$80,000 a year. That's an estimated \$52 million in annual income to mine workers living

in the region. If 50 percent of those workers lived and shopped in Ely it would potentially inject up to \$26 million in local income each year into Ely's economy. That is the plus side of the ledger.

So what does the negative side of the ledger look like if, as critics of the mine fear, North Country enthusiasts choose to look elsewhere to invest in new homes and seasonal cabins should a new mine impact the local environment and the culture of Ely? A new mine could bring \$26 million in annual income to local residents. Could it also lead to the loss of existing or future local income if new investment in surrounding townships slows and some current residents choose to leave the area, taking their incomes with them? And, if so, how much?

To better understand this issue, and assess the potential downside risks of copper-nickel mining to Ely's economy, it is important to understand the townships that surround Ely, and how they differ (often significantly) from the city itself. The four townships we examined were: Eagles Nest, Fall Lake, Morse, and Stony River.

The townships differ from Ely in several ways, including: average annual income, housing stock growth, total property valuation, and views on mining. We'll look at the data on each of these topics. We'll also offer potential conclusions to better assess the level of economic risk that copper-nickel mining poses to the Ely area economy.

Household income

The income divide between the city of Ely and its surrounding townships is significant. According to the most recent census data, the average household income in the four townships is as follows:

% Eagles Nest: \$60,000

% Fall Lake: \$74,000

% Morse: \$76,825

% Stony River: \$47,500

Note that we used the mean, or average, rather than the median household income, because our goal was to determine total income to residents of each township, which is best determined by multiplying the average household income times the number of households.

Using this calculation, we can determine that year-round residents of the four townships earn approximately \$77.8 million annually, which represents income available for economic activity within the Ely area economy. The mean household income in the city of Ely is \$45,800. Using the same calculation for the city of Ely, with 1,681 total households, you get \$76.98 million in annual income. These calculations demonstrate the importance of the townships in generating income to the Ely area economy.

But this only tells part of the story, because it does not consider the impact of seasonal recreational property owners, who outnumber permanent residents of the townships by roughly two-to-one, and who spend a significant portion of their annual income in the Ely area as well.

Determining the annual household income of seasonal residents and other recreational property owners in the area is not possible, but we can assume it is greater than the average income for permanent residents, since most of these property owners are living in urban areas where incomes tend to be greater. For the purposes of our analysis, we assumed that seasonal and recreational property owners earned 25 percent more than year-round residents (which we believe is conservative).

We also assumed that seasonal and recreational property owners utilized their residences an average of six weeks a year, and spent 20 percent of their income on living expenses while in the area or on maintenance, utilities, insurance, and other expenses related to their seasonal residence, many of which are incurred year-round.

Adding seasonal recreational income on this basis adds \$31.37 million to the total available for economic activity in the Ely area. We recognize some of that season recreational property is owned by residents of Ely proper, and we are deducting ten percent to account for that, giving a grand total of added income to the area of \$28.3 million.

This leaves a grand total of \$106 million in annual income generated by residents in the townships, compared to \$76.98 million generated by residents of Ely.

Growth in housing

While growth in housing is relatively modest throughout northern St. Louis County, it is relatively robust in three of the four townships surrounding Ely, and seasonal residences dominate the new construction. We compared census data from 2000 and 2010, and during that decade the four townships saw the following growth in housing stock:

Eagles Nest: 27 percent overall, 26 percent in seasonal recreational.

Fall Lake: 14 percent overall, 22 percent in seasonal recreational.

Morse: 16 percent overall, 21 percent in seasonal recreational.

Stony River: Two percent overall, 11 percent in seasonal recreational.

By contrast, Ely experienced five percent growth in housing stock over the decade. That means Ely added 110 new housing units over the decade, or an average of 11 new units annually. The townships, by contrast, added 517 units over the same period, or just under 52 per year. For those sectors reliant on housing stock growth, such as construction, building supplies, excavators, well drillers, finance, insurance, home furnishings, the housing growth in Eagles Nest, Morse, and Fall Lake townships is a critical element of Ely's economy.

Assuming a relatively conservative average overall construction price of \$150,000 for a new housing unit in the townships, this sector alone would inject \$7.8 million annually into the Ely area economy.

Views on copper-nickel mining

At last week's scoping hearing on the proposed federal mineral withdrawal, Ely Mayor Chuck Novak claimed that 68 percent of the residents of Ely supported a new mine. Other data would tend to support that figure, within the city itself.

It is a much different story, however, in the townships, where the evidence points to majority or near-majority opposition to a new mine among permanent residents.

Consider the results of the 2015 DFL special election primary, which pitted three pro-copper mining DFLers against a candidate, Bill Hanson, who took a strong position against it. In a normal race, Hanson, who hails from Grand Marais, would have been unable to mount a strong bid in the Ely area, particularly with an Ely area candidate also in the race. But Hanson's position on mining enabled him to significantly outperform expectations in the townships. While Hanson garnered 23 percent of the vote in the city of Ely, he won 56 percent of the vote in the four-way race in Fall Lake, 57 percent in Eagles Nest, 62 percent in Stony River, and was the top vote-getter (albeit narrowly) in Morse, with 37 percent of the vote.

Such vote totals reflect the views of permanent residents, whereas there is general agreement in the area that the views of seasonal residents are even more strongly opposed to copper-nickel mining than these vote totals would suggest.

A 2014 survey of attitudes in the four townships paints a similar picture. The survey, completed by researchers from the University of Minnesota-Morris, enjoyed a strong rate of response from those who received the survey.

It asked, among other things, what qualities attracted township residents to the area. The vast majority cited their proximity to nature, outdoor recreational opportunities, solitude, and peace and quiet as the primary factors that keep them in the region.

When asked what factors would make them consider leaving the area, the single largest factor (named by 23 percent of respondents) was mining. Based on this data, it is apparent that a significant divide in views on copper-nickel mining exists between residents of the city of Ely and residents of neighboring townships.

Property valuation

Differences between the city of Ely and the four townships in terms of property valuation are equally stark. Morse and Fall Lake townships are among the highest value townships in northern Minnesota, with total estimated market value of \$414 million and \$345 million respectively. Eagles Nest Township's 2017 valuation is \$109 million, while Stony River's valuation is \$88 million. That's a combined valuation of \$956 million.

The valuation of all property within the city of Ely, by contrast, is \$164.5 million.

Economic studies have demonstrated that proximity to a mine, or other developments considered undesirable to most residential property owners, can negatively impact property values.

What does it mean?

The data presented here could support differing interpretations and predictions of the future, but several conclusions are well justified. They include:

- Collectively, both permanent and seasonal residents of the townships provide roughly six of every ten dollars of locally-based income available to generate economic activity in Ely.
- Collectively, the townships account for 82 percent of new housing construction activity in the Ely area. They provide an overwhelming amount of the real estate activity as well.
- While the permanent populations of the townships are currently static, the overall population of both permanent and seasonal residents is growing modestly in three of the four townships (Stony River being the exception). If that trend continues, it would continue to provide for income growth in the Ely area, resulting both from annual construction wages as well as from spending from growth in the overall number of seasonal residents.
- Majorities of both year-round and seasonal residents of the townships would view copper-nickel mining in the Ely area as a significant and negative development that could prompt a significant percentage to consider leaving the area. How large a percentage is unknown, and that presents an economic risk associated with a mining proposal.
- The sluggish pace of new housing construction in Stony River township from 2000-2015, which was a period during which mineral exploration activity was intense in the township, may reflect future conditions in other townships, particularly Fall Lake, were copper-nickel mining to commence.
- Should 15 percent of current township residents choose to leave the area or visit seasonal homes less frequently due to mining, it would lead to an initial loss of \$15.9 million in annual income to the Ely area economy. Should 20 percent of township residents choose to leave or visit less frequently, it would lead to an initial loss of \$21.2 million. Recall that based on the township survey, 23 percent said that mining was a factor that could prompt them to leave the area. As the recent study led by economist Spencer Phillips noted, approximately 42 percent of residents of the region rely on investment income and transfer payments, such as Social Security for their income, which leaves them much freer to leave an area if the attributes that currently keep them in the area are lost or impaired.

It is likely that most of these individuals would choose to sell their properties, many of which would be purchased by others, very possibly by new or existing residents working in a new mining operation. But substituting one income for another maintains the economic status quo. It does not generate economic growth. Given that average incomes for township residents are relatively high, replacing current township residents with future miners provides little gain in overall local income.

- The potential losses in local income would compound with time due to lost growth. From 2010-2015, according to census data, average income in Morse and Fall Lake Townships increased by 3.2 percent annually, which added approximately \$2.1 million per year in local income to the Ely area without accounting for the impact of new seasonal residents investing in, and spending time in, the townships. By contrast, incomes for Ely residents have remained static over the past five years, according to census data. It is reasonable to conclude that the economic importance of the

townships to the Ely area economy would continue to increase over time, barring a development that discourages new investment in the townships and slows or halts the increase in township incomes due to the loss of high earners who choose to leave the area. This could be considered an “opportunity cost” of mining, as the Ely area loses income gains that township residents might otherwise accrue.

- The introduction of mining would likely have a considerable negative impact on future growth in seasonal recreational real estate purchases and housing unit construction in the townships. That appears to already be happening in Stony River Township due to the impact of intensive mineral exploration there. The start-up of mining, on the other hand, may increase housing construction within the city of Ely, which could partially offset a decline in construction in the townships.

- Based on consistent historical trends, overall local wage income derived by residents employed in a copper-nickel mine would tend to decline over time given increasing mechanization and productivity gains. For example, it required four times as many mine workers in 1979 to produce the same tonnage of taconite as is produced on the Iron Range today. Economists project that the pace of mechanization will only increase, leading to less overall wage income generated by any operating mine over time.

- Stability versus boom and bust. The amenity-based economic model that is well-established in Ely’s townships provides a relatively robust, predictable, and steadily growing source of income to local residents that generates activity within the local economy. A copper-nickel mine would provide a robust source of local income during boom years, but would provide significant economic stress during the cyclical downturns inherent in the mining industry. Mining busts create significant economic dislocation and hardship in mining-dependent communities. That is a conclusion well supported by historical data.

Impact of lost tourism

None of this analysis considers potential impacts to what is typically called the tourism economy, which focuses on income generated through visits by non-residents. A recent study that looked solely at income generated by outside visitors utilizing the Boundary Waters Canoe Area Wilderness, concluded that the wilderness generated about \$57 million in annual income to the communities of Ely, Tofte, and Grand Marais. Were negative perceptions about copper-nickel mining within the wilderness to affect visitation, the costs would almost certainly be focused in the Ely area, where the effects of the mine would be most pronounced. Conservatively, 50 percent of wilderness visits emanate from Ely.

Were wilderness visits beginning from Ely area accesses to decline by 25 percent due to negative perceptions of sulfide mining within the wilderness watershed, it would result in the loss of more than \$7 million in annual local income. Keep in mind that wilderness visits comprise only a portion of the total visitor spending in Ely. The total impact on visitor spending could be significantly greater than \$7 million annually.

Conclusions

While the opening of a copper-nickel mine near Ely would provide a significant new source of local income to the community, it would not come without significant economic risks, which could offset or even exceed the benefits of a mining venture.

Based on this analysis, it is reasonable to assume that the opening of a mine could lead to the initial loss of anywhere from \$22.9 million to \$28.6 million in local income, a figure that would likely increase over time.

This assumes losses based primarily on public perception of the loss of wilderness attributes in the Ely area. Significant documented environmental impacts, a major spill, or a catastrophic event, such as a tailings basin breach, could significantly increase the downside risks to the Ely area economy.

**AN ANALYSIS OF A TWIN METALS PROJECT:
RISKS VS BENEFITS
BY MARSHALL HELMBERGER, THE TIMBERJAY
TOWER, MINNESOTA
FALL 2017**

Twin Metals: Risks vs Benefit

Summary:

Benefits: \$18-20 million in new mining wages in the community

Risks: Conservatively threatens loss of \$18-\$21 million in local income in the four townships surrounding Ely, due to loss of amenity-based residents, and slowdown in township housing market. Additional risk of loss of \$7-\$10 million in outside tourism spending related to BWCAW, possibly much more. **Total potential income loss: \$25-\$31 million**

The Debate:

Industry has miscast the debate as: "Mining vs Tourism"

Tourism has a role in amenity-based economy, but is not, by itself, the foundation for a strong and stable economy. Tourism attracts outside dollars seasonally and provides the ongoing flow of visitors, some of whom will become residents. Amenity-based residents provide a local and sustainable source of income that fuels the local economy.

This is what is threatened by Twin Metals.

The Townships and the amenity-based economy:

Ely's surrounding townships are home to a diverse mix of relatively high income permanent and seasonal residents who drive the Ely economy through their spending. Their total income exceeds the annual income generated by all residents of Ely by a significant margin. The townships represent Ely's "Golden Goose" in the sense that their year-round spending maintains viability for Main Street businesses.

Average & total income of residents

Twp./City	Avg. income	Total income
Eagles Nest	\$60,000	\$7.5 million
Fall Lake	\$74,000	\$20.7 million
Morse	\$76,825	\$45.4 million
Stony River	\$47,500	\$4.3 million
Total income/townships		\$77.9 million
City of Ely	\$45,800	\$77.0 million

Source: U.S. Census/American Fact Finder
Does not include seasonal residents

New housing units 2000-2010

Twp./City	Number	% increase
Eagles Nest	131	37%
Fall Lake	134	17%
Morse	219	19.6%
Stony River	33	9.5%
Total units	517	20%
City of Ely	110	5.7%

Source: U.S. Census/American Fact Finder
Includes both permanent and seasonal housing

Housing growth

From 2000-2010, the townships saw a 20 increase in housing, totaling 517 new units based on census data. The entire city of Ely saw 110 new housing units during the same period. Housing drives numerous sectors of the economy, including construction, real estate, finance, insurance, and retail. Assuming an average new home price of just \$150,000, new housing in the townships generates \$7.8 million in mostly local spending. The one exception to the township growth trend is Stony River, where the bulk of Twin Metals exploratory drilling has taken place. Housing growth there was less than half of other Ely area townships. If this is connected to Twin Metals' activity, this should be a major concern.

What attracts people to live in the townships?

Township study by U of M-Morris researchers found:

➤ Top 8 reasons for choosing to live in the area: Nature/Environment/Wildlife, Solitude and Privacy, Beauty, Peace/Quiet, Recreation, BWCA/lake access, Enjoy area/quality of life, Clean undeveloped environment.

These are lifestyle reasons. People are NOT locating in the townships for existing jobs. They are bringing their jobs or incomes with them or creating new opportunity locally.

Township study also asked residents what kinds of activities would cause them to leave the area. Mining topped the list, with 23 percent indicating they would consider leaving if mining was approved.

Most township residents oppose sulfide mining

Attitudes in the townships differ sharply from the city of Ely. Bill Hansen was the top vote-getter in every outlying township from Ely in the 2015 DFL primary. In a four-way race, Hansen received 62 percent of the vote in Stony River, 56 percent in Fall Lake, 57 percent in Eagles Nest, and 37 percent in Morse. By contrast, Hansen received 24 percent of the vote in Ely.

The economic risk:

Were mining to create an outmigration of some current residents, Ely stands to lose more in terms of local income to sustain its economy than mining would generate.

Compare the numbers:

Twin Metals: Projects 650 jobs, but given the trend of mechanization in the industry that would likely be 500 jobs by the time a mine could open, 15-20 years from now. BLS statistics show an average wage for a miner of \$72,365. But that is when miners are working. In the real world, they are subject to frequent layoff. Over a ten-year period, assume 18 months on layoff, at 50 percent of usual salary. That equals an average annual salary of \$66,945.

Assume 60 percent of miners live and spend in the Ely area.
This totals \$20 million in new income for the Ely area.

But what are the potential costs?

- If just 15 percent of township residents opt to leave, or seasonal residents visit less frequently, that represents a loss of approximately \$15-18 million in local income annually.
- If new housing development in the townships slows by just a third, that's a loss of approximately \$3 million annually.
- These numbers only reflect loss of income from existing or potential LOCAL residents.

➤ **THIS DOES NOT INCLUDE LOST TOURISM \$\$**

Potential lost tourism

- BWCAW traffic alone generates over \$25 million in annual income to the Ely economy, extrapolating from the recent study commissioned by Friends of the Boundary Waters. Perception of a pristine wilderness is critical to continued interest in visiting the BWCAW.
- Reducing visitation and spending by just 25 percent would represent a loss of approximately \$6-\$8 million annually.
- Add it all up: Potential loss of income of approximately \$24-29 million annually, perhaps much more.

It's unknowable right now, which makes it a significant risk.
An economic study should be done, which would be part of the Forest Service withdrawal study

Bottom line:

Mining may very well reduce total income that fuels the Ely's economy.

Other factors:

- Job numbers and overall local income generated by mining declines over time. CAN ONLY BE SUSTAINED BY NEW MINES .
 - That increases risks of environmental harm, intensifies industrialization and negative impacts that undermine the amenity-based economy.
-

- Amenity-based economy offers potential for sustained and diversified economic growth in locally-generated income, as long as the amenities that attract people to the area are not diminished.

Backing Twin Metals is high risk for limited reward

- Project is not currently economical
- Unlikely to happen within 15 years, if ever
- It provides NO REMEDY for Ely's current economic challenges
- Were a mine eventually built, it remains unclear whether the local economy would benefit, or suffer as a result.

Why seek renewal of leases?

- Renewal of leases doesn't make the project any more economical. Doesn't make it any safer or any less unpopular around the state, or in the townships.
- It only guarantees another 15-20 years of bitter division in the Ely area.
- It risks slowing new investment in housing and business by increasing the element of risk the longer the debate goes on
- It risks strangling the Golden Goose, even if mining never occurs.

The fight hurts Ely

- People don't like living in a community that is divided.
 - Local businesses are being targeted for online attacks
 - This is an unhealthy dynamic that only harms Ely's efforts to build its amenity-based economy
-



Antofagasta's Takeover of Duluth Metals: Timeline

July 9, 2014—Twin Metals project on shaky grounds?

On July 3, when many Americans were on vacation and U.S. financial markets were slow, Chilean mining giant Antofagasta PLC announced that it would not exercise its option to acquire an additional 25% interest in Twin Metals.

If Duluth Metals Ltd., the other investor in Twin Metals, wishes to proceed despite Antofagasta's rejection, it must find a source for the hundreds of millions of dollars of financing that would be required for the project to go forward.

While Duluth Metals has struggled to portray the Antofagasta decision in the best possible light, Antofagasta has obviously lost confidence in Twin Metals. In announcing the decision, Antofagasta's chief executive officer stated that the company intends to prioritize "projects with the highest value and the lowest risks...." We believe that Antofagasta's refusal to invest additional money in Twin Metals reflects its assessment that the costs associated with mining in the priceless Boundary Waters watershed far outweigh any potential economic benefit.

The market has responded by driving the value of Duluth Metals to a 52 week low. An independent analysis of Duluth Metals now rates it as a sector "underperformer." The newsletter Proactive Investors stated that "[t]he way forward for Duluth is unclear at this time."¹

Analysts Meyer and Galison observed that there have been "limited disclosures since the [Twin Metals] 2009 scoping study," and went on to write that "[t]he timing of Antofagasta's departure ahead of the public release of the pre-feasibility highlights also gives us pause." While Twin Metals previously claimed that its so-called prefeasibility study would be released in June 2014, it now states only that "highlights" of a "Pre-feasibility Study Technical Report" will be released in July.

Federal and Minnesota policy makers must carefully consider these latest developments. Antofagasta's decision and the financial bind that Duluth Metals now faces demonstrate plainly the hollowness of company promises to provide adequate financing to mine sulfide ore safely and to deal

¹ <http://www.proactiveinvestors.com/companies/news/55237/duluth-metals-sinks-to-52-week-low-as-cibC-CutS-Drice-target-55237.html>

with the permanent pollution that sulfide ore mines generate. The Twin Metals proposal fails all tests. It is not scientifically safe, and an adequate financial backstop is non-existent.

October 13, 2014—Twin Metals “pre-feasibility study” shows the project should not be considered feasible

The market responded promptly in July by driving the value of Duluth Metals stock to a 52 week low. Securities analysts Meyer and Galison observed that “[t]he timing of Antofagasta’s departure ahead of the public release of the pre-feasibility highlights...gives us pause.” Twin Metals had claimed that its so-called pre-feasibility study would be released in June 2014. In fact, it was not released until Friday, October 3, 2014; the content shows some obvious reasons for concern, and the market punished Duluth Metals again, with stock trading as low as 15 cents per share on October 9, which is a decline in value of 90% over the last year. Among the many staggering problems that the Twin Metals project faces are the failure to prove as yet that its technology will deliver economically viable copper concentrate from one of the major deposits; a projected internal rate of return of only 11.4% (assuming copper prices at \$3.50 per pound; on October 10, 2014 the price was \$3.03 per pound), when investors typically seek between 15% and 30%; and the financial condition of Duluth Metals, which is seeking to raise \$5 million through investors for “certain development expenses for the Twin Metals Minnesota project and general corporate purposes.” A project that will require at least \$2.77 billion to develop is without credibility when its controlling shareholder is scraping for \$5 million.

The foregoing demonstrates plainly the hollowness of company promises to provide adequate financing to mine sulfide ore safely and to deal with the permanent pollution that sulfide ore mines generate. Recent experience in British Columbia shows what happens when mining companies cut corners. On August 4, 2014 the dam at the over-filled tailings basin at the Mount Polley copper and gold mine burst, with the result that 24 million cubic meters of mine tailings and waste water laden with heavy metals (including arsenic, mercury, zinc, lead, cadmium, and selenium, among others) wiped out several kilometers of Hazeltine Creek, filling it with debris, and then poured into Quesnel Lake. One of the largest sockeye salmon nurseries in British Columbia, Quesnel Lake is a vital rearing area for salmon that spawn in the world-famous Fraser River system. The heavy metals deposited in the lake will be taken up in the water column and the food chain, and may affect one-quarter of British Columbia’s sockeye salmon in the years ahead. Local residents who draw their drinking water from Quesnel Lake and other nearby waters are seriously concerned about the health impacts of consuming the metal-laden waters.

November 12, 2014—Antofagasta acquisition of Duluth Metals raises worrisome questions

After Duluth Metals has struggled unsuccessfully since July to raise even minimal amounts of operating cash, and after its stock fell to a low of 7 cents per share on October 31, 2014 (it traded at US\$3.32 per share in 2010), Antofagasta has signed an agreement to buy Duluth Metals for US\$0.40 per share. The deal also apparently includes an undertaking by Antofagasta to pay off Duluth Metals’ convertible debentures. When final, the transaction will cost Antofagasta between \$50 million and \$100 million, and will leave it with complete control of all Duluth Metals and Twin Metals assets, including more than 65,000 acres of mineral leases, prospecting permits, and exploration rights within the boundaries of the Superior National Forest. A map depicting these properties is attached.

It appears to be true that the project designed by Twin Metals as described in its 43-101 document (“Technical Report on Pre-feasibility Study, Amended: 6 October 2014”) is so expensive that the costs far outweigh the benefits. Obviously aware of the environmental and political challenges of mining in the Boundary Waters watershed, Twin Metals developed an elaborate plan for a massive

underground mine and thousands of acres of surface infrastructure, with huge tunnels and pipeline systems many miles in length to transport ore, water, and tailings. Twin Metals made much of its plans (i) ultimately to return some sulfide-bearing waste rock to mine tunnels, and (ii) to transport tailings through an aboveground pipeline more than 12 miles long from the concentrator to a 7,000 acre outdoor tailings storage facility site south of the Laurentian Divide and thus outside the watershed of the Boundary Waters. Nevertheless, reports from experts Dr. Tom Myers, Dr. Lawrence Baker, and Dr. Lee Frelich have shown that the elaborate plans touted by Twin Metals are inadequate to prevent significant long-lasting damage to the Superior National Forest and the Boundary Waters. The Twin Metals pre-feasibility study pegged the capital costs of the project at 2.775 billion dollars.

In announcing its acquisition of Duluth Metals, Antofagasta said in part, “[W]e believe that the Duluth Complex is an attractive deposit and upon closing of the offer *we will commence the process of re-evaluating the [Twin Metals] projects design* while also continuing with the permitting activities” (emphasis added). Our fear is that “*re-evaluating the project’s design*” means that Antofagasta has abandoned all pretense of concern about the devastation that would be caused by sulfide-ore mining, and may turn to a plan that involves open-pit mining, permanent above-ground storage of sulfide-bearing waste rock, and a tailings storage basin on thousands of acres of land near the concentrator facility, north of the Laurentian Divide.

Our concern is not speculative. The Pre-feasibility Study admits that Twin Metals developed a groundwater flow model for a possible open-pit mine at the Maturi Southwest deposit (Twin Metals proposed to mine four different deposits). At page 14-30, the Pre-Feasibility Study states “[a]lthough the resource classification [of the Maturi Southwest deposit] is based on an underground mining scenario, the deposit will likely be mined to the surface at some point in the future; thus a 15 ft thick skin at the surface was removed from classification to account for the average overburden over the area.” Further, on October 27, 2014, Edison Investment Research Limited, which counts Duluth Metals as one of its clients, issued a report comparing the Twin Metals plan unfavorably with three other “greenfield” copper mining projects: Rosemont in Arizona, USA; Taca Taca in Argentina; and Las Bambas in Peru. All three of those projects are planned as open-pit projects. According to the Edison report, the “capital intensity” in US dollars invested per pound of copper to be produced in those three projects is, respectively, \$4.8, \$5.6, and \$8.6. The Twin Metals Pre-Feasibility Study capital intensity stands in sharp contrast at the greatly higher amount of US\$13.7 US per pound of copper. The inescapable conclusion is that the Twin Metals underground mine plan set forth in the Pre-feasibility Study does not work in the marketplace. In a report issued on November 11, 2014 addressing Antofagasta’s acquisition of Duluth Metals, Edison wrote “[w]e expect Antofagasta (ANTO) to complete the relevant feasibility studies, albeit on its own timelines, and /or the eventual scope of the TMM project to be vastly different from that given in the [Pre-feasibility Study]” (emphasis added).

In July, when Antofagasta waived its right to acquire a controlling interest, its total investment in Twin Metals in equity and loans was more than \$250 million. In the statement issued following the recent signing of the acquisition agreement, Antofagasta said that “[t]he acquisition of Duluth provides Antofagasta with a long-term option to develop a large polymetallic resource in a stable and proven mining region.” Antofagasta apparently decided to throw good money after bad, most likely because it expects to develop open-pit mines at the deposits it controls along the South Kawishiwi River and Birch Lake, and elsewhere on the more than 65,000 acres of mineral interests that it now controls.

The Pre-Feasibility Study plan for underground mines was bad enough, but open pit mines and permanent above-ground storage of sulfide-bearing ore and tailings over thousands of acres of land in

the heart of the Superior National Forest, in the watershed of the Boundary Waters, would constitute poison and destruction on a catastrophic scale. The current sustainable wilderness-edge economy and hundreds of millions of dollars in vacation and retirement home investment in the Ely area would be devastated. Minnesota and U.S. policy makers must not (1) jeopardize the Boundary Waters Wilderness and its watershed nor (2) expose taxpayers to billions of dollars of costs to clean up the disaster that an Antofagasta mine would be.

January 21, 2015—Antofagasta fully acquires Duluth Metals

On January 21, Antofagasta completed the takeover of Duluth Metals and achieved 100% ownership of Twin Metals. The final purchase price was US\$79 million, which included US\$43.5 million in Duluth Metals shares. Antofagasta CEO Diego Hernandez reaffirmed the long-term nature of Twin Metals, saying, “The completion of the Duluth acquisition is a positive next step in building the company’s long-term growth pipeline.”² He also stated in an interview with the Chilean financial newspaper *Diario Financiero* that Twin Metals wouldn’t occur within the next four years.³

Despite Antofagasta’s recent acquisition, Twin Metals still compares unfavorably to other copper mines, including Antofagasta’s own projects. Twin Metals’s pre-feasibility study predicts a total capital expenditure of \$2.8 billion to produce 50,000 tons per year of copper concentrate, which would have to be further processed elsewhere to create cathode copper. For comparison, Antofagasta is about to begin constructing their Antucoya project, an open-pit mine 70% owned by Antofagasta with a total capital expenditure of \$1.9 billion. Antucoya would produce 80,000 tons per year of cathode copper, which is directly marketable to the global commodities market. To achieve a more favorable comparison with its own projects, Antofagasta would likely have to drastically cut costs or otherwise redesign the mine plan.

The consolidation of ownership to a single Chilean mining company with no connection to Minnesota or the Boundary Waters only confirms concerns that the development of a massive sulfide-ore copper mining district would threaten the Boundary Waters Wilderness and the region it supports.

² http://www.virginiamn.com/news/local/antofagasta-acquires-duluth-metals/article_df7d5db8-a1dc-11e4-ac3e-d71c37322ee7.html

³ <https://www.df.cl/noticias/empresas/actualidad/grupo-luksic-logra-avance-definitivo-en-internacionalizacion-de-negocio-minero/2015-01-16/170744.html>

Materials delivered to USFS (DC) and BLM ES (3 sets each agency) December 12 - 14, 2017 and USFS (SNF) on December 18, 2017:

1. Table of Contents of printed materials delivered in October to SNF and BLM ES
2. The Science Updated (October 2017)
3. Technical Memorandum: Twin Metals Mining and the Boundary Waters Canoe Area Wilderness, Risk Assessment for Underground Metals Mining, dated August 8, 2014 (1 copy per agency)
4. Acid mine drainage risks – A modeling approach to siting mine facilities in Northern Minnesota USA, Journal of Hydrology 533 (2016) 277-290
5. Description and copies of 4 new peer-reviewed MPCA-sponsored sulfate studies - NEW
 - a. Myers modeling used the transport of sulfate into the BWCAW
6. Dr. Engstrom scoping letter dated August 10, 2017
 - a. Engstrom identified himself as one of scientists working on MPCA sulfate studies; recommends withdrawal
7. American Fisheries Association Position Paper and Policy on Mining and Fossil Fuel Extraction, December 29, 2015
 - a. EIS and public involvement in deciding whether a mine is most appropriate use of land and water, particularly relative to the need to preserve ecologically and culturally significant areas
8. Predicting Water Quality Problems at Hardrock Mines, Maest & Kuipers, December 2006
 - a. Predictions error rate higher if high acid mine drainage and near water
9. Pages from Technical Document Acid Mine Drainage Prediction, EPA, December 1994; Cover page, ii, 38 – 40 (Duluth Complex)
10. Northmet/ PolyMet Water Quality Modeling Data Charts (Duluth Complex) SDEIS and FEIS- NEW
11. Photo Essay showing proximity to water – NEW
12. Earthworks 14-mine Summary of Copper Mines
13. The Track Record of Water Quality Impacts Resulting from Pipeline Spills, Tailings Failures and Water Collection and Treatment Failures, Earthworks, November 2012
14. Sulfide-Ore Copper Mining and/or A Sustainable Boundary Waters Economy: The Need to Consider Real Tradeoffs, Key-Log Economics LLC, October 2017 UPDATED
15. Key-Log Report Summary
16. Timberjay Study Summary
17. Township Impact In copper-nickel debate, we should consider economic costs as well as gains, Timberjay, August 3, 2017
18. Ely's Golden Goose Township residents power Ely-area economy, Timberjay, August 3, 2017
19. Timberjay Study Outline Presented to IRRRB Commissioner, Fall 2017 – NEW
20. 'Watch out, Ely: Mine robots are on the way; Are jobs obsolete? Automation in the industry is coming – and it's sooner than we think' Commentary by Paul and Sue Schurke, October 20, 2017, StarTribune - NEW

- a. 'The Robots Are Coming,' October 1, 2017, Mining Magazine;
<http://www.miningmagazine.com/sponsor-showcase/maclean-engineering-sponsor-showcase/the-robots-are-coming/>
 - b. 'Mining a Mirage,' a key global planning study by the International Institute for Sustainable Development and Columbia Center on Sustainable Investment, September 2016;
<http://www.iisd.org/library/mining-mirage-reassessing-shared-value-paradigm-light-technological-advances-mining-sector>
21. 'Robots will run mines within the next decade, Anglo says,' November 30, 2017, Information Management; <https://www.information-management.com/articles/robots-will-run-mines-within-the-next-decade-anglo-says> - NEW

**Water Quality Modeling Results for
Copper (Cu), Lead (Pb), and Sulfate
(SO₄) at Plant and Mine Sites,
Northmet (PolyMet) Project**

**Supplemental Draft EIS
2013**

**A Sulfide-Ore Copper/Nickel Mine
Proposed to be Developed in the
Duluth Complex of Minnesota**

**Mitigation will be required for at
least 200 years at the Mine Site and
500 years at the Processing Site**

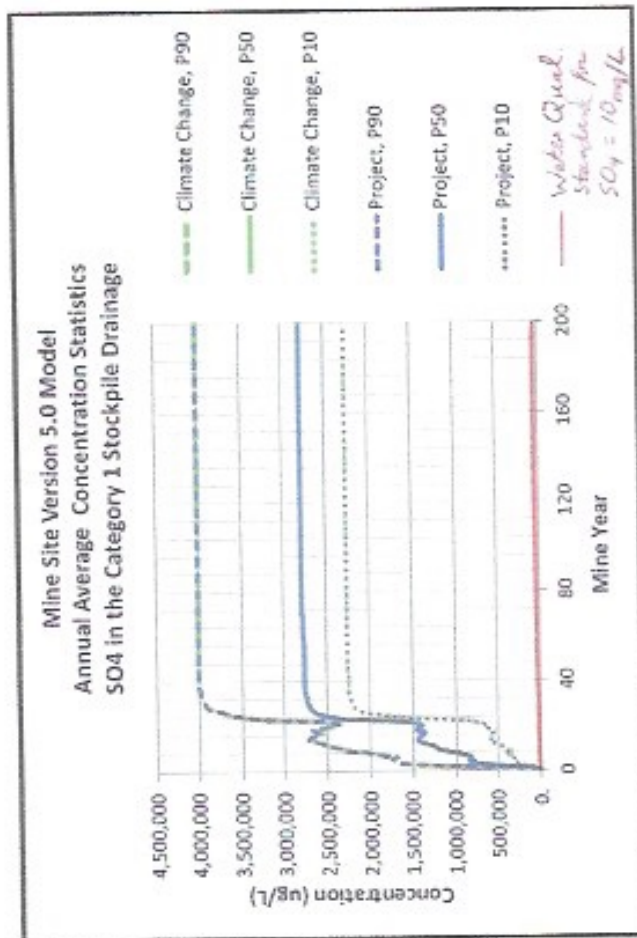


Figure 6-169 Sulfate in the Category 1 Waste Rock Stockpile drainage; with and without modeled Climate Change

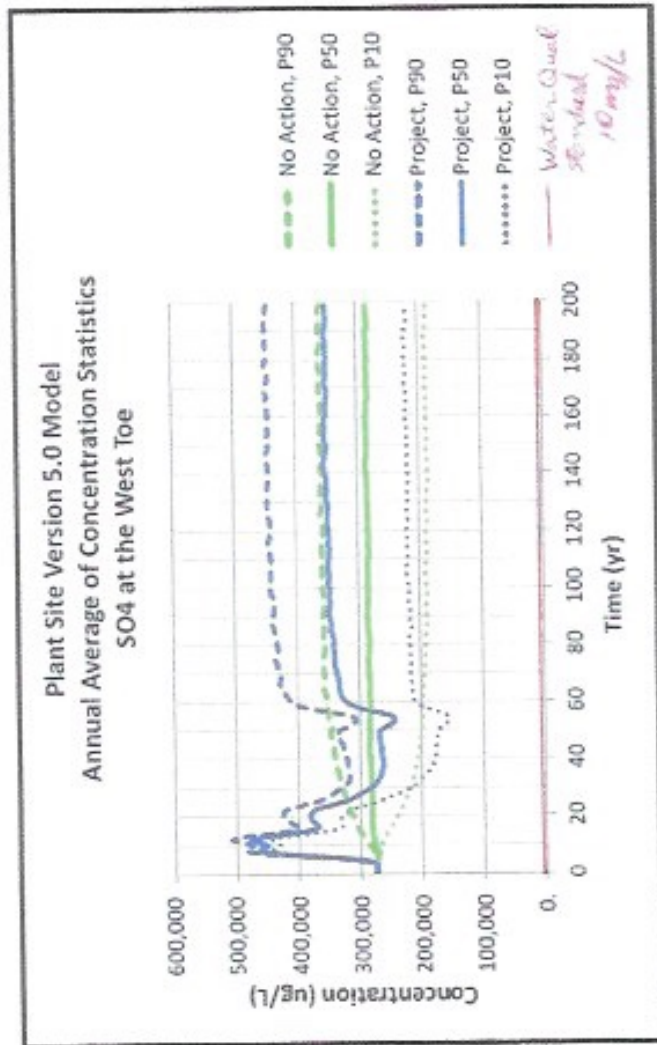


Figure 6-42 Sulfate Concentrations at the West Toe; No Action vs. Project

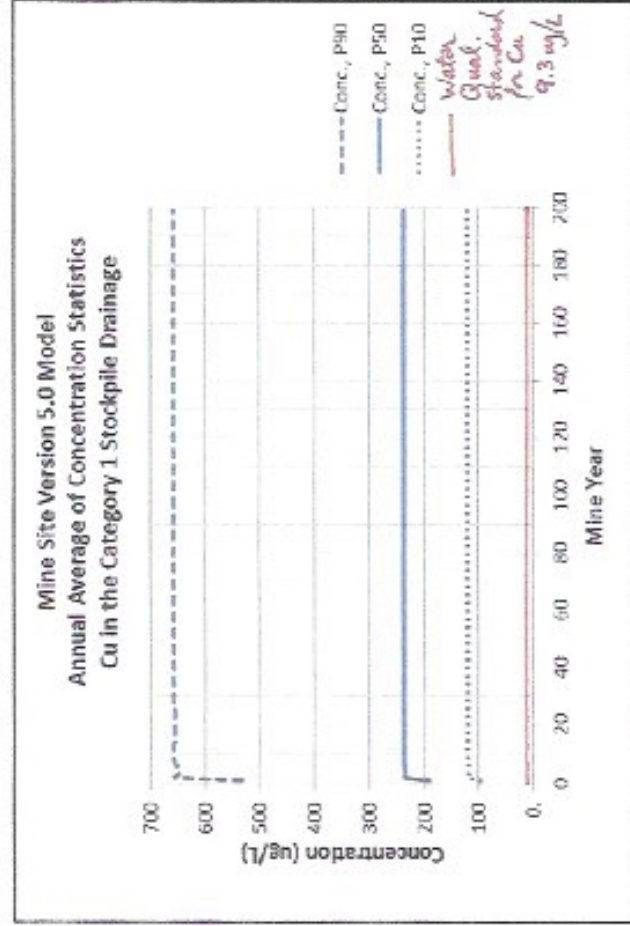


Figure 6-33 Estimated Copper Concentrations in the Category 1 Stockpile Drainage

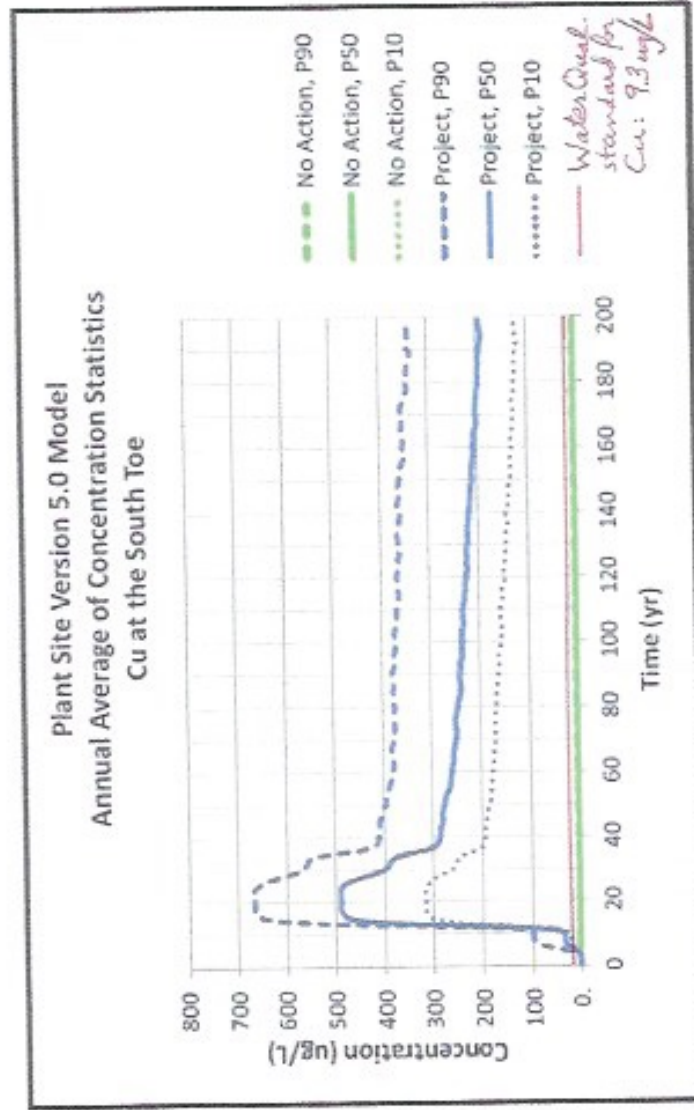


Figure 6-49 Copper Concentrations at the South Toe: No Action vs. Project

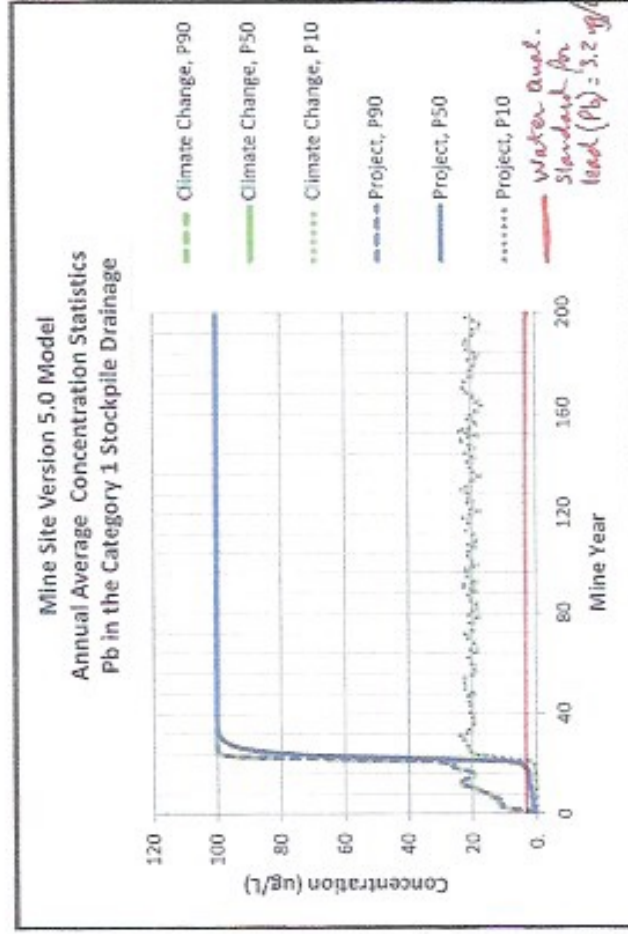


Figure 6-168 Lead in the Category 1 Waste Rock Stockpile drainage with and without modeled Climate Change

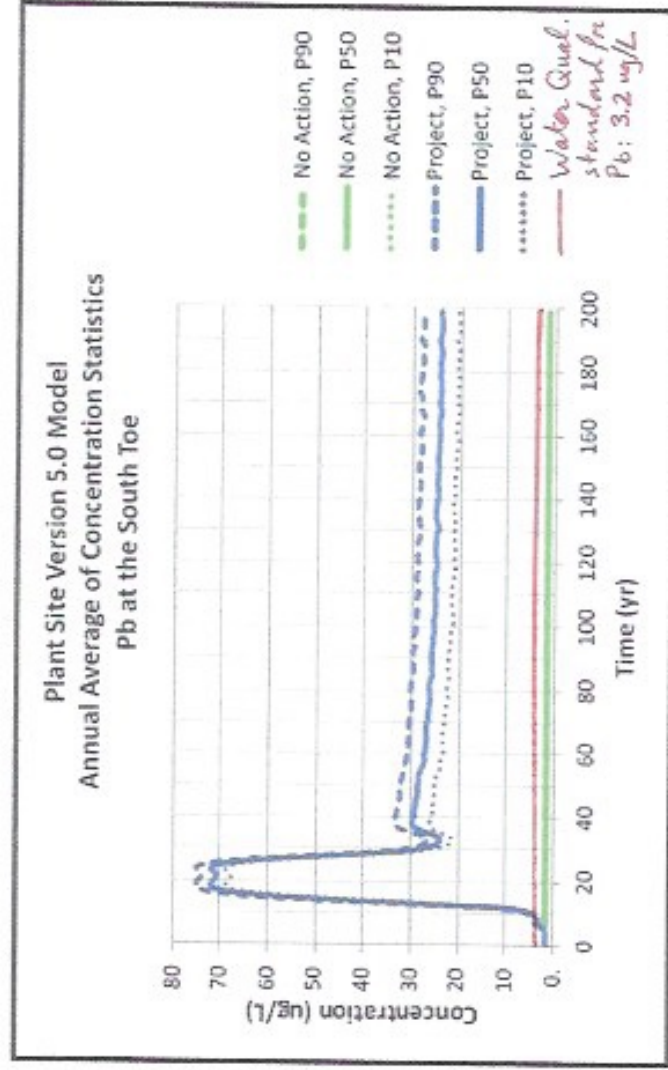


Figure 6-50 Lead Concentrations at the South Toe; No Action vs. Project

Duluth Metals

Buy now, pay later

Pre-feasibility study

Metals & mining

Duluth's PFS highlights the Twin Metals Minnesota (TMM) project as an economically viable Tier 1 asset at reasonable long-term commodity price forecasts. With Antofagasta recently deciding not to increase its ownership and reverting to a conventional 40% funding equity interest, options for TMM's development lead to an increased focus on the Barclays strategic review currently underway. Finding a suitable Tier 1 asset developer capable of funding multi-billion dollar projects is limited to a small pool of large mining companies. Recent M&A activity in the copper space highlights such companies are buying Tier 1 assets to fit longer-term growth profiles.

Year end	Revenue (C\$m)	PBT* (C\$m)	EPS* (C\$)	DPS (C\$)	P/E (x)	Yield (%)
12/11	0.0	(36.2)	(0.21)	0.0	N/A	N/A
12/12	0.0	(54.9)	(0.30)	0.0	N/A	N/A
12/13	0.0	(58.3)	(0.32)	0.0	N/A	N/A
12/14e	0.0	(37.7)	(0.25)	0.0	N/A	N/A

Note: *PBT and EPS are normalised, excluding intangible amortisation, exceptional items and share-based payments.

Taca Taca sale hints at TMM's value

A review of recent transactions in the copper space identifies the First Quantum acquisition of Taca Taca from Lumina Copper in August 2014 as the most comparable project successfully sold. Our review identifies Taca Taca as comparable in resource size, initial capex and technical understanding. Taca Taca was bought for US\$0.43bn or US\$33 per total copper resource tonne. Applying this multiple to Duluth's 60% attributable copper resource of 7.4Mt implies a potential value of US\$245m. Taca Taca is located in the Puna region of Argentina.

Pre-feasibility provides first, but not final, details

The Twin Metals PFS details an initial development scope for the TMM project, with a 50k short-ton per day (45k metric tonnes per day) plant producing c 101k short-tons of copper in concentrate pa with a secondary nickel concentrate with gold, platinum and palladium credits (but not silver, which could add additional future value). Capital intensity is high presently (US\$167/t annual mill throughput), due to a conservative PFS. Further, there are indications that mines elsewhere have built similar plants for much less. For example, First Quantum's 7Mtpa Kevitsa plant in Finland cost US\$430m.

Valuation: TMM value range US\$0.87-3.68/share

We value Duluth on the basis of its in situ resource and PFS. Valuing the copper only using resource multiples derived from First Quantum's purchase of Taca Taca and Edison's in-house copper multiple implies a value for Duluth's 60%-owned resource of US\$1.79/share and US\$2.74/share respectively. Valuing the entire resource (Cu, Ni, Pt, Pd and Au) using our in-house resource multiples results in a value of US\$3.68/share (60% ownership). This compares with the TMM's PFS value of (C\$0.99/share (US\$0.87/share).

27 October 2014

Price **C\$0.13**

Market cap **C\$18m**

US\$0.89/C\$

Net debt (C\$m) at 30 June 2014 29.2

Shares in issue 136.8m

Free float 85%

Code DM

Primary exchange TSX

Secondary exchange N/A

Share price performance



%	1m	3m	12m
Abs	(51.0)	(73.4)	(86.6)
Rel (local)	(49.0)	(71.9)	(87.7)
52-week high/low	C\$1.2	C\$0.1	

Business description

Duluth Metals is a TSX-listed Canadian company focused on investigating the Twin Metals Minnesota copper-nickel-cobalt-platinum-palladium-gold-silver project held in JV with Antofagasta (40%) and exploring for similar deposits in NE Minnesota, US.

Next event

Outcome of strategic review TBC

Analysts

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[Edison profile page](#)

Resource value US\$1.79 to US\$3.68/share for DM's 60%

The recent publication of Duluth's PFS prompts us to update our forecasts and valuation and to assess Duluth's strategic options. Since our last detailed outlook note in June 2013, [Steadily unlocking value](#), market conditions have changed materially, notably in terms of reduced eurozone economic confidence, slower growth in China and depressed commodity prices.

The Twin Metals project is a Tier 1 2.4bn tonne resource of mainly copper and nickel, with potentially significant credits from palladium, platinum and gold located in Minnesota, US. The PFS points to economic viability based on a total capex of US\$2.8bn. The project is owned 60% Duluth, 40% Antofagasta. Whereas we had previously expected that Antofagasta might increase its 40% stake and share of funding, Antofagasta has now stated that it will retain its holding at 40%. This gives Duluth a clearer base on which to define its strategic plan and it has commissioned Barclays to review options.

In this note we have reviewed our forecasts; we retain the 60/40% Duluth/Antofagasta structure, and in the interests of visibility we do not include any assumptions of future equity issuance (although this is always a possibility). Our 2014 cash flow estimates point to an end-year funding requirement of around C\$51m.

Meanwhile, we have undertaken a review of our valuation. We examine values from three perspectives, which we comment on in more detail in this note and summarise as follows:

1. Resource and reserves: using our in-house resource multiples, we derive a value of US\$3.68 a share for Duluth's 60% attributable resource.
2. Comparable industry transactions: we have reviewed relevant industry transactions from the last year, and relate them to the TMM resource, from which we infer a value of US\$1.79 (based on, in our view, the most appropriate Taca Taca acquisition by First Quantum).
3. PFS-based valuation: using assumptions in the PFS, we ascribe a value of C\$0.99 per share. We note and discuss upside potential to this from increased payability and a lower capex scenario

First valuation: Edison-derived resource value: US\$1.79/share

In the first of our three valuation methodologies we value the TMM project using Edison's in-house multiples derived from the current market's perception of in situ resource values. We use the TMM resource data as laid out in Exhibit 2.

Using these in-house resource multiples and recent M&A activity (Exhibit 4), we value the TMM project as shown in Exhibit 1. We provide values based on Duluth's current ownership of 60% and also at 100% ownership.

Exhibit 1: In-situ resource valuations per Duluth share at 60% and 100% ownership			
	Copper resource multiple (US\$/t)	DM ownership and value per DM share	
Copper resource valued		60%	100%
Rosemont	144	7.81	13.01
Taca Taca	33	1.79	2.98
Edison	51	2.74	4.56
All metals valued			
Total resource value	Various	3.68	6.14
Source: Edison Investment Research			

Exhibit 2: TMM mineral resources

	Metal grade							Metal quantities					
	Tonnes	Cu	Ni	Pt	Pd	Au	3PGE	Cu	Ni	Pt	Pd	Au	3PGE
0.3% Cu cut-off	Mt	%	%	g/t	g/t	g/t	g/t	Mt	Mt	Moz	Moz	Moz	Moz
Maturi													
Measured	279	0.63	0.20	0.15	0.34	0.08	0.57	1.76	0.56	1.31	2.76	0.68	4.63
Indicated	746	0.58	0.19	0.16	0.35	0.08	0.59	4.33	1.42	3.72	7.61	1.81	12.79
Inferred	482	0.49	0.16	0.14	0.31	0.07	0.52	2.36	0.77	2.14	4.41	0.98	7.33
Maturi Southwest													
Indicated	93	0.48	0.17	0.08	0.185	0.048	0.31	0.45	0.16	0.07	0.16	0.04	0.27
Inferred	29	0.43	0.15	0.07	0.157	0.041	0.26	0.11	0.04	0.02	0.04	0.01	0.07
Birch Lake													
Indicated	91	0.52	0.16	0.23	0.51	0.11	0.86	0.47	0.15	0.68	1.35	0.30	2.27
Inferred	217	0.46	0.15	0.18	0.37	0.09	0.64	1.00	0.33	1.25	2.34	0.55	4.03
Spruce Road													
Indicated	-	-	-	-	-	-	-	-	-	-	-	-	-
Inferred	435	0.43	0.16	-	-	-	-	1.87	0.70	-	-	-	-
Total													
Measured	279	-	-	-	-	-	-	1.76	0.56	1.31	2.76	0.68	4.63
Indicated	930	0.56	0.17	0.15	0.33	0.08	0.56	5.25	1.72	4.47	9.12	2.15	15.32
Inferred	1,163	0.46	0.15	0.09	0.20	0.05	0.33	5.34	1.84	3.41	6.79	1.54	11.43
Total resource	2,372.29	0.52	0.17	0.39	0.79	0.18	1.32	12.35	4.12	9.19	18.68	4.37	31.39

Source: Duluth Metals and Edison Investment Research

In-situ resource multiples

Our in-situ resource valuations are based on the mineral resource above, our in-house resource multiples (Exhibit 3) and EV/t values derived from the successful sale of Taca Taca by Lumina Copper and Rosemont by Augusta Copper.

Exhibit 3: Edison-derived resource multiples and gross resource value

Metal	Total contained metal (Mt)	Edison derived resource multiples		In-situ resource value (US\$m)
Copper	12.35	US\$/t	50.53	624
Nickel	4.12	US\$/t	9.46	39
Gold	4.37	US\$/oz	10.31	45
Platinum equivalent	27.87	US\$/oz	4.72	132

Source: Edison Investment Research

Second valuation: Comparable transaction, Taca Taca best peer

The following exhibit highlights three recent transactions in the copper space. The constituents were chosen on the basis of how recent the transactions are, their resource and reserve base size and general project attributes. It is notable that a successful transaction appears to warrant a capital intensity figure of around US\$40-50 per annual tonne of milling capacity. Duluth's current capital intensity is relatively high, in our view, at around US\$167/t.

Exhibit 4: Review of recent transactions

Current owner	Duluth Metals	Hubday Minerals	FirstQuantum	MMG
Project	Twin Metals Minnesota project	Rosemont	Taca-Taca	Las Bambas
Ownership	60%	100%	100%	62.5%
JV partner(s)	Antofagasta (40%)	N/A	N/A	Guoxin Int'l Investment Co Ltd (22.5%) and CITIC Metal Co. Ltd (15.0%)
Status	Planned	Planned	Planned	In development
Technical confidence level	Pre-Feasibility Study Level	Updated Feasibility Study	Preliminary Economic Assessment	N/A
Location	Minnesota, USA	Arizona, USA	Puna region, Argentina	Apurimac region, Peru
Fraser Mineral Potential index rating	44/96	15/96	54/96 (based on the nearby Salta region)	38/96
Resource and Reserve information on a 100% basis				
Proven and Probable Reserves (billion lbs Cu)	6.20	5.87	N/A	15.21
Project resources inclusive of reserves (billion lbs Cu)	27.20	8.57	28.70	23.15
Weighted average copper resource grade (%)	0.55	0.39	0.44	0.61
Recovery (Cu %)	85.6%	87.0%	90.2%	87.0%
Product sold	Copper and nickel concentrates	Copper and molybdenum concentrate	Copper concentrate	Copper concentrate
Annual copper production (Metric ktpa)	92	100	244	315
LOM cash costs (net of by-product credits)	US\$0.76/lb	US\$1.02/lb	US\$1.11/lb	US\$0.81/lb
Comment	• Pre-development underground project • Approx. US\$200m of pre-development capital sunk by partner Antofagasta • 100% ownership of approximately 40,000 acres of exploration mineral interests adjacent and near to the TMM project			
Initial capex	US\$2.77bn	US\$1.06bn	US\$3.00bn	US\$6.00bn* (of which US\$3.50bn sunk prior to sale)
Copper price used in base case	US\$3.50/lb	US\$3.50/lb	US\$2.75/lb	N/A
Transaction basis and valuation (100% basis)	N/A	Shares and warrants	Either shares, cash or a combination thereof	All cash
Bought from	N/A	Augusta Resource Corp.	Lumina Copper	Glencore
Transaction announced	N/A	February 11 2014, revised June 23 2014	August 19 2014	April 12 2014
Transaction value	52*	US\$0.56bn	US\$0.43bn	US\$5.85bn
EV of vendor* or project value per attributable Cu lb (US\$)	0.003	0.065	0.015	0.207
Capital intensity (US\$/lb Cu)	13.7	4.8	5.6	8.6
Annual mill (metric) tonnage throughput (on a 365 day basis)	16,556,126	29,801,027	65,700,000	51,100,000
Capital intensity per annual tonne of throughput	167	36	46	117
Capital intensity per tonne of copper output	30,232	10,601	12,295	19,048

Source: Edison Investment Research. Note: *On 16 October MMG reported it will take US\$2.7bn–3.2bn to complete the project. Resource and reserves based on a 100% ownership. Capital saving required to bring Duluth's capital intensity down to US\$50/t is US\$1.94bn.

Third valuation: PFS-based TMM value and inputs

We also provide a valuation based on the TMM PFS (filed with Sedar on 3 October 2014). However, the amount of further work required in nearly all aspects of the project limits the PFS's appropriateness as a definitive value for the TMM project.

Based on the assumptions provided in the following section, with Duluth retaining 60% ownership and Antofagasta remaining at 40%, and with first production occurring in 2020, we value Duluth on a DCF basis at C\$0.99 per share (using a 10% discount rate to reflect general equity risk). This valuation is undiluted to reflect the value of the TMM project on a standalone basis.

Unit conversion – all units in this report are metric

Units in the draft-PFS are imperial. For the purposes of this report and to aid comparison with other projects and companies, we have converted all units to their metric equivalent. This also applies to our valuation of the TMM. Our valuation uses Duluth's pre-feasibility study on the TMM project dated 20 August 2014.

Reserves

Publication of the PFS means that for the first time a valuation for the TMM project can be made using an ore reserve estimate. The previous 2009 preliminary economic assessment (PEA) only used mineral resources to define a mining schedule. The current reserve estimate is given in the following exhibit.

Exhibit 5: TMM ore reserves							
	Tonnes	Cu	Ni	Pt	Pd	Au	Ag
0.3% Cu cut-off	Mt	%	%	g/t	g/t	ppm	ppm
Maturi							
Proven	118	0.65	0.21	0.152	0.354	0.09	2.31
Probable	318	0.59	0.19	0.163	0.367	0.09	2.15
P&P	436	0.61	0.19	0.160	0.363	0.09	2.19
Maturi Southwest							
Proven	0	0	0	0	0	0	0
Probable	39	0.48	0.16	0.083	0.192	0.05	1.60
P&P	39	0.48	0.16	0.083	0.192	0.05	1.60
Total							
Proven	118	0.65	0.21	0.152	0.354	0.09	2.31
Probable	360	0.58	0.19	0.154	0.348	0.08	2.09
P&P	478	0.59	0.19	0.154	0.349	0.08	2.14

Source: Duluth Metals and Edison Investment Research

Factors that may affect the mineral reserve estimate

The reserve estimate (Exhibit 5) should be viewed in conjunction with the following factors in mind:

- Metal price and exchange rate assumptions. The reserve estimate currently uses US\$3.00/lb (copper), US\$9.50/lb (nickel), US\$1,200/oz (gold), US\$1,650/oz (platinum) and US\$700/oz (palladium). A downward revision in the nickel price could have a material impact on the portion of the mineral resource available for conversion to the ore reserve.
- Assumptions relating to geotechnical and hydrogeological parameters used in mine design. Geotechnical drilling needs to be performed and therefore could change the mine plan based on changes in rock conditions.
- Assumptions that go into defining the NSR cut-off used to constrain mineral reserves. Concentrate marketability is not yet defined and requires much more work, especially on the nickel concentrate and also the Maturi Southwest ores.

- Appropriate dilution control being able to be maintained. This will depend on adequate geotechnical drilling and calculation of rock mass characteristics.
- Assumptions as to the paste backfill strengths and quantities required, again requiring further geotechnical investigation.
- Mining and metallurgical recovery assumptions, which will require greater definition of mine plans (accounting for geotechnical inputs) and process flow sheet designs.
- Changes to capital and operating cost estimates. Along with any changes to commodity price assumptions, capex and opex cost changes will likely materially affect the scope of mining the TMM project.
- Changes to royalty payment assumptions.
- Variations to the permitting, operating or social licence regime assumption. This point will need to be clarified as part of a bankable feasibility study, which has not yet been financed or completed.

Current metallurgical recoveries

Exhibit 6 details the outcome of Duluth's previous metallurgical testing of TMM ore samples. The two concentrates to be produced via sequential flotation are a main copper concentrate and a secondary nickel concentrate. Importantly, both concentrates are clean of any deleterious elements, reducing the risk of incurring smelter penalties.

The tailings produced from the flotation process will be very low in sulphur. Half of all tailings produced will be stored in a conventional tailings facility, with the other half being used to paste backfill mine workings.

Exhibit 6: Concentrate recovery factors

Metal	Cu concentrate (%)	Ni concentrate (%)	Cumulative (%)
Copper	85.75	7.99	93.74
Nickel	6.70	55.50	62.20
Gold	64.69	13.32	78.01
Palladium	38.84	35.99	74.83
Platinum	23.90	39.20	63.10
Silver	64.43	12.46	76.89

Source: Duluth Metals Draft-PFS announcement of 20 August 2014

A 45,000 metric tpd (50k stpd) concentrator will house a single process line of SAG (semi-autonomous grinding) and ball milling, followed by sequential copper and nickel flotation. The concentrator site will also house all ancillary infrastructures including storage, rail load-out facility, tailings thickener, filter plant and concentrate receiving system.

Payability

We have used metal payability values based on Duluth's ore reserve assumptions. These assumptions are given in Exhibit 7. However, Duluth notes that significant work still remains in understanding the mineralogy and payability of TMM ores.

Exhibit 7: Concentrate payability assumptions

Commodity	Reserve payability assumption
Copper	76.4%
Nickel	70.8%
Gold	45.0%
Platinum	69.3%
Palladium	68.6%

Source: Duluth Metals PFS ore reserve statement

Operating costs

The following operating cost estimates are used in our PFS valuation. These will likely change, especially with a definitive processing method for the concentrates still undecided.

Exhibit 8: Operating costs		
Cost	Unit	Value
Mining	US\$/t	11.39
Processing	US\$/t	3.62
G&A	US\$/t	2.44
Surface operating cost	US\$/t	2.26
Total onsite operating cost	US\$/t	19.71
Source: Duluth Metals Draft PFS announcement of 20 August 2014		

Capital expenditure

The PFS details the following capital expenditure estimates. We note capex as one of the main differentiators between those projects that have been successfully sold and the TMM. Capital intensity of the TMM is US\$167 per tonne of annual processing capacity, compared with Rosemont (US\$36/t), Taca Taca (US\$46/t) and Las Bambas (US\$117/t). The PFS provides estimates with a c ±25% accuracy, and should be viewed as a starting indication of the project's potential scope. In our view and in current market conditions, the initial capital required needs to be significantly decreased to the level of either Taca Taca or Rosemont in order to attract a potential buyer for the project. However, to reduce capex by such a level may not be possible due to the low-grade nature of the deposit. Only further investigation will produce an answer as to whether capex can be reduced significantly.

Exhibit 9: Capital expenditure estimate		
Project area	Unit	Value
Mine	US\$m	793
Concentrator	US\$m	956
Tailings management	US\$m	547
Surface infrastructure and utilities	US\$m	379
Owner's costs	US\$m	100
Total capital cost	US\$m	2,775
Source: Duluth Metals Draft-PFS announcement of 20 August 2014		

Commodity prices

Our PFS-based valuation uses the commodity prices listed below. The production of nickel and copper (or any metal) is an extremely energy-intensive process and the price of a barrel of crude oil can therefore be considered as a proxy for energy input costs generally. As a result, the correlation between the nominal price of nickel or copper and the nominal price of oil historically has been extremely close. The future price of nickel and copper can therefore be estimated in terms of the price of crude oil by using regression techniques. The result of this analysis results in our long-term price forecasts for copper, nickel, platinum and palladium, reflecting current spot prices, in the following exhibit.

Exhibit 10: Edison's long-term commodity prices		
Commodity	Unit	Value
Copper	US\$/lb	2.96
Nickel	US\$/lb	9.95
Gold	US\$/oz	Various
Platinum	US\$/oz	1,400
Palladium	US\$/oz	800
Source: Edison Investment Research		

Gold price forecast – accounts for actual 2013 US monetary base

Our gold price deck is shown in Exhibit 11 below. These numbers are based on the forecast given in our November 2013 sector report, [Gold – US\\$2,070 by 2020](#). We have adjusted them for the US monetary base as reported for 2013 and 2014 ytd.

Exhibit 11: Edison's gold price forecasts

Calendar year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Gold price (US\$/oz)	1,381	1,334	1,402	1,485	1,474	1,420	1,420	1,411	1,407	1,433	1,466	1,481	1,496
Calendar year	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	
Gold price (US\$/oz)		1,472	1,465	1,473	1,492	1,510	1,556	1,615	1,663	1,705	1,821	2,178	2,483

Source: Edison Investment Research

Sensitivities

The material increase in capex, reduced payability and our commodity price assumptions have the biggest impacts on the valuation of the TMM project. Further work is required to refine capital expenditure estimates, the metallurgy of Maturi Southwest ores (which at present is poorly understood according to the PFS), payability and marketability of concentrates and the ore reserve estimates of the deposit. The results of these work programmes could materially change the scope of the TMM project.

Payability

Metallurgical upside exists from improving the rejection of non-sulfide gangue from the nickel concentrate and piloting the fine-tuned baseline and pyrrhotite rejection processes. Duluth's consultants suggest that piloting Maturi material leads to significantly better metallurgy than testing the same material in the laboratory. Duluth consultants state a third area of potentially significant upside by enhancing the payability of the precious metals in the concentrate.

Concentrate quality

Duluth's consultant Wood Mackenzie in the PFS highlights that: "The nickel content in the copper concentrate could attract a minor penalty which usually is applied at 0.5% Ni+Co and the typical nickel content of the proposed concentrate is 0.65%Ni. The penalty is not expected to be material but could restrict the marketability of this material."

Further metallurgical test programmes should improve the marketability of all concentrates.

Metallurgy

The PFS states that the replication of the final flow sheet and final flow sheet results still needs to be undertaken, stating that: "Specifically, the need and operation of in-circuit thickening needs to be firmed up with the optimized flow sheet, while the pyrrhotite rejection process needs further development to enhance nickel recoveries, and pilot plant confirmation testing. The other major source of metallurgical process risk lies in the processing of Maturi South west mineralization, as this is very poorly understood at the present time."

A complete understanding of the metallurgy of TMM ores could materially increase or decrease project economics.

Financials

At end June 2014 Duluth had net debt of US\$29.2m. With Antofagasta remaining at 40% ownership and reverting to a 40% funding equity interest, we wait for Duluth to announce a strategic way forward for the project. Historical cash burn rates are no longer relevant due to the uncertainty surrounding further development of the TMM project. We expect Duluth to materially reduce its capital expenditure and exploration programmes to conserve cash at least until the outcome of the Barclays strategic review. No timetable has been set for completion of this review.

Exhibit 12: Financial summary

	C\$m	2011	2012	2013	2014e
		IFRS	IFRS	IFRS	IFRS
PROFIT & LOSS					
31-December					
Revenue		0.0	0.0	0.0	0.0
Cost of Sales		0.0	0.0	0.0	0.0
Gross Profit		0.0	0.0	0.0	0.0
EBITDA		(13.5)	(13.2)	(12.0)	(2.9)
Operating Profit (before amort. and except.)		(13.6)	(13.4)	(12.2)	(3.1)
Intangible Amortisation		0.0	0.0	0.0	0.0
Exceptionals		2.1	0.0	0.0	0.0
Share-based payments		(3.7)	(3.7)	(4.7)	(4.0)
Operating Profit		(15.2)	(17.1)	(16.9)	(7.1)
Net Interest		(0.8)	1.0	(5.3)	(3.8)
Share of JV PBT		(21.9)	(42.6)	(40.8)	(30.7)
Profit Before Tax (norm)		(36.2)	(54.9)	(58.3)	(37.7)
Profit Before Tax (FRS 3)		(37.9)	(58.6)	(63.0)	(41.7)
Tax		11.4	18.4	19.8	3.8
Profit After Tax (norm)		(24.8)	(36.6)	(38.5)	(33.9)
Profit After Tax (FRS 3)		(26.5)	(40.3)	(43.2)	(37.9)
Average Number of Shares Outstanding (m)		121.5	125.6	125.8	136.8
EPS - normalised (C\$)		(0.21)	(0.30)	(0.32)	(0.25)
EPS - normalised and fully diluted (C\$)		(0.21)	(0.30)	(0.32)	(0.25)
EPS - (IFRS) (C\$)		(0.22)	(0.32)	(0.34)	(0.28)
Dividend per share (C\$)		0.0	0.0	0.0	0.0
Gross Margin (%)		N/A	N/A	N/A	N/A
EBITDA Margin (%)		N/A	N/A	N/A	N/A
Operating Margin (before GW and except.) (%)		N/A	N/A	N/A	N/A
BALANCE SHEET					
Fixed Assets		194.8	156.8	151.0	138.4
Intangible Assets		0.0	0.0	0.0	0.0
Tangible Assets		1.1	1.3	1.1	1.3
Investments		193.7	155.6	149.9	137.1
Current Assets		28.1	14.1	9.9	0.4
Stocks		0.0	0.0	0.0	0.0
Debtors		0.4	0.1	0.3	0.3
Cash		27.6	14.0	9.5	0.0
Other		0.1	0.1	0.1	0.1
Current Liabilities		(1.4)	(1.8)	(0.7)	(15.4)
Creditors		(1.4)	(1.6)	(0.7)	(0.7)
Short term borrowings		0.0	(0.2)	0.0	(14.7)
Long Term Liabilities		(39.3)	(29.8)	(38.0)	(35.8)
Long term borrowings		(0.4)	(10.1)	(35.1)	(35.8)
Other long term liabilities		(38.9)	(19.7)	(2.9)	0.0
Net Assets		182.2	139.3	122.2	87.6
CASH FLOW					
Operating Cash Flow		(13.4)	(12.3)	(13.0)	(5.9)
Net Interest		0.4	0.1	(3.3)	(0.7)
Tax		0.0	0.0	0.0	0.0
Capex		(1.0)	(0.4)	(0.0)	(0.4)
Acquisitions/disposals		(34.9)	(9.8)	(19.1)	(17.9)
Financing		21.1	(0.9)	0.1	0.0
Dividends		0.0	0.0	0.0	0.0
Net Cash Flow		(27.7)	(23.5)	(35.4)	(24.9)
Opening net debt/(cash)		(24.7)	(27.2)	(3.6)	25.6
HP finance leases initiated		0.0	0.0	0.0	0.0
Other		30.1	(0.1)	6.3	0.0
Closing net debt/(cash)		(27.2)	(3.6)	25.6	50.5

Source: Company accounts and Edison Investment Research

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Duluth Metals

Duluth's JV partner Antofagasta buys TMM

Antofagasta has made an offer to buy all of Duluth Metal's outstanding shares at C\$0.45 each in cash. All things considered this is a good deal for Duluth's shareholders; Antofagasta is one of the few majors that could have the ability to develop the Twin Metals Minnesota (TMM) project, a Tier 1 asset. A decision as to whether the deal will be through a plan of arrangement or a takeover bid will be made by mid-November. The shareholder approval meeting is estimated to be in early January 2015.

Year end	Revenue (C\$m)	PBT* (C\$m)	EPS* (C\$)	DPS (C\$)	P/E (x)	Yield (%)
12/11	0.0	(36.2)	(0.21)	0.0	N/A	N/A
12/12	0.0	(54.9)	(0.30)	0.0	N/A	N/A
12/13	0.0	(58.3)	(0.32)	0.0	N/A	N/A

Note: *PBT and EPS are normalised, excluding intangible amortisation, exceptional items and share-based payments.

PFS provides a first pass look at value

The TMM pre-feasibility study (PFS), announced in summary form first on 20 August, detailed an initial development scope for the TMM project. It outlined a 50k short ton per day (45k metric tonnes per day) plant producing c 101k short tons of copper in concentrate pa. The project also carried significant revenues from secondary nickel concentrate with minor gold, platinum and palladium credits (but not silver, which could add additional future value). Capital intensity is high presently (US\$167/t annual mill throughput), due to a conservative PFS. We expect Antofagasta (ANTO) to complete the relevant feasibility studies, albeit on its own timelines, and for the eventual scope of the TMM project to be vastly different from that given in the PFS.

Bridge loan terms extended, and other conditions

Under the terms of the offer, ANTO would provide Duluth with a C\$2.3m private placement at C\$0.45 per share to assist funding it through to completion of the takeover. ANTO is also eligible for a C\$3.5m termination fee if the deal does not complete in specified circumstances. Further, ANTO has agreed to extend the term of the currently outstanding (c US\$10m) bridge loan by 12 months, and if the deal closes will assume the C\$30m convertible debenture announced by Duluth on 10 April 2013. The definitive acquisition agreement will be finalised by 21 November 2014 subject to a due diligence condition being satisfied by Duluth or waived by ANTO. The offer is also subject to a two-thirds tender or approval condition.

Valuation: Duluth's resource valued at C\$9.1/Cu t

Duluth's 60% attributable copper resource is 7.4Mt; ANTO's offer implies a per copper tonne value of C\$9.1 (US\$8.3) compared with our in-house copper resource tonne multiple of C\$46.00 (US\$41.75). The large difference between the sale value and our resource multiple probably reflects the size of the low-confidence inferred category material (constituting 43% of the total resource), and the amount of work required to understand the economic viability of the TMM project. Removing inferred material, the announced transaction places a value on each of the indicated and measured tonnes of C\$16.1 (US\$14.6).

Antofagasta takeover

Metals & mining

11 November 2014

Price C\$0.42
Market cap C\$57m

US\$/C\$:0.90

Net debt (C\$m) at 30 June 2014 29.2

Shares in issue 136.8m

Free float 85%

Code DM

Primary exchange TSX

Secondary exchange N/A

Share price performance



Business description

Duluth Metals is a TSX-listed Canadian company focused on investigating the Twin Metals Minnesota copper-nickel-cobalt-platinum-palladium-gold-silver project held in JV with Antofagasta (40%) and exploring for similar deposits in NE Minnesota, US.

Next events

Estimated sale completion date 21 November 2014

Analysts

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[Edison profile page](#)

Exhibit 1: Financial summary

	C\$m	2011	2012	2013
		IFRS	IFRS	IFRS
PROFIT & LOSS				
31-December				
Revenue		0.0	0.0	0.0
Cost of Sales		0.0	0.0	0.0
Gross Profit		0.0	0.0	0.0
EBITDA		(13.5)	(13.2)	(12.0)
Operating Profit (before amort. and except.)		(13.6)	(13.4)	(12.2)
Intangible Amortisation		0.0	0.0	0.0
Exceptionals		2.1	0.0	0.0
Share-based payments		(3.7)	(3.7)	(4.7)
Operating Profit		(15.2)	(17.1)	(16.9)
Net Interest		(0.8)	1.0	(5.3)
Share of JV PBT		(21.9)	(42.6)	(40.8)
Profit Before Tax (norm)		(36.2)	(54.9)	(58.3)
Profit Before Tax (FRS 3)		(37.9)	(58.6)	(63.0)
Tax		11.4	18.4	19.8
Profit After Tax (norm)		(24.8)	(36.6)	(38.5)
Profit After Tax (FRS 3)		(26.5)	(40.3)	(43.2)
Average Number of Shares Outstanding (m)		121.5	125.6	125.8
EPS - normalised (C\$)		(0.21)	(0.30)	(0.32)
EPS - normalised and fully diluted (C\$)		(0.21)	(0.30)	(0.32)
EPS - (IFRS) (C\$)		(0.22)	(0.32)	(0.34)
Dividend per share (C\$)		0.0	0.0	0.0
Gross Margin (%)		N/A	N/A	N/A
EBITDA Margin (%)		N/A	N/A	N/A
Operating Margin (before GW and except.) (%)		N/A	N/A	N/A
BALANCE SHEET				
Fixed Assets		194.8	156.8	151.0
Intangible Assets		0.0	0.0	0.0
Tangible Assets		1.1	1.3	1.1
Investments		193.7	155.6	149.9
Current Assets		28.1	14.1	9.9
Stocks		0.0	0.0	0.0
Debtors		0.4	0.1	0.3
Cash		27.6	14.0	9.5
Other		0.1	0.1	0.1
Current Liabilities		(1.4)	(1.8)	(0.7)
Creditors		(1.4)	(1.6)	(0.7)
Short term borrowings		0.0	(0.2)	0.0
Long Term Liabilities		(39.3)	(29.8)	(38.0)
Long term borrowings		(0.4)	(10.1)	(35.1)
Other long term liabilities		(38.9)	(19.7)	(2.9)
Net Assets		182.2	139.3	122.2
CASH FLOW				
Operating Cash Flow		(13.4)	(12.3)	(13.0)
Net Interest		0.4	0.1	(3.3)
Tax		0.0	0.0	0.0
Capex		(1.0)	(0.4)	(0.0)
Acquisitions/disposals		(34.9)	(9.8)	(19.1)
Financing		21.1	(0.9)	0.1
Dividends		0.0	0.0	0.0
Net Cash Flow		(27.7)	(23.5)	(35.4)
Opening net debt/(cash)		(24.7)	(27.2)	(3.6)
HP finance leases initiated		0.0	0.0	0.0
Other		30.1	(0.1)	6.3
Closing net debt/(cash)		(27.2)	(3.6)	25.6

Source: Duluth Metals accounts and Edison Investment Research

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August 10, 2017

To: US Forest Service

From: Dr. Daniel R. Engstrom
Director, St. Croix Watershed Research Station
Science Museum of Minnesota
St. Paul and Marine on St. Croix, MN

Re: Northern Minnesota Federal Mineral Withdrawal EIS #50938

As one of the lead scientists studying the effects of sulfate on mercury cycling, wild rice, and sulfur biogeochemistry in Minnesota, I wish to enter into the public record my professional concerns regarding the risks posed by the operation of metal-sulfide mining within the Rainy River Watershed, including waters of the Boundary Waters Canoe Area Wilderness. The information summarized below is referenced primarily to a series of recent peer-reviewed scientific publications regarding the biogeochemical effects of sulfate loading to surface waters (wetlands, streams, and lakes) on mercury methylation, wild-rice growth and survival, and aquatic chemistry. The comments mostly pertain to sulfate, with or without the added impacts of lowered pH (acid drainage), and also to the relative sensitivity of the receiving waters to potential sulfate discharges. Although the studies on which these comments are based were carried out as part of my professional employment, the views expressed herein are my own and do not represent any formal position taken on this subject by my employer, the Science Museum of Minnesota.

Background / Standing

I am a Ph.D. research scientist with the Science Museum of Minnesota, where I serve as Director of the St. Croix Watershed Research Station, the Museum's environmental research center. I've held this position for 18 years and in that capacity supervise a team of research scientists with expertise in hydrology, biogeochemistry, environmental engineering, and aquatic biology. I also hold appointments as Adjunct Professor in the Department of Earth Sciences and the Water Resources Science Program at the University of Minnesota. I've worked specifically in the field of mercury fate and transport for three decades and have authored more than 35 journal articles and book chapters on the subject – several among the most highly cited in the field (Swain et al. 1992, Fitzgerald et al. 1998, Lindberg et al. 2007). This research has been heavily focused on boreal ecosystems, but also includes work in Arctic and southeast Alaska, the Canadian Maritimes, and the tropics (Florida, South America, East Africa). I've served on numerous scientific panels tasked with advancing understanding of human impacts on mercury cycling and contamination.

Specific to the issues surrounding sulfide-metal mining, I directed a multi-institution, 9-year ecosystem scale experiment on the effects of atmospheric sulfate deposition on mercury methylation in a boreal peatland at the Marcell Experimental Forest (USFS Northern Research Station) (Jeremiason et al. 2006, Coleman Wasik et al. 2012, Coleman Wasik et al. 2015, Strickman et al. 2016). These efforts were followed by a multi-year study, coordinated by the

Minnesota DNR, on the biogeochemical consequences of sulfate pollution from iron mining activities in the St. Louis River watershed of northern Minnesota (Berndt and Bavin 2011, 2012, Berndt et al. 2016, Jeremiason et al. 2016, Johnson et al. 2016, Bailey et al. 2017). This investigation also focused on the effects of sulfate on mercury cycling and methylation, but in systems of contrasting and highly elevated sulfate concentrations (as compared to the Marcell wetland). Finally, I participated in a Minnesota Pollution Control Agency (MPCA) investigation of the effects of sulfate on the growth and survival of wild rice (*Zizania palustris*) (Myrbo et al. 2017a, Myrbo et al. 2017b, Pastor et al. 2017, Pollman et al. 2017). The purpose of the study was to evaluate Minnesota's existing 10-mg/L sulfate standard for the protection of wild rice waters through a combination of field, laboratory, and experimental mesocosm approaches.

Biogeochemical Cascade

Sulfate serves a key biogeochemical role in aquatic environments where the availability of oxygen often limits the bacterial decomposition of organic matter. Under anoxic conditions that frequently prevail in sediments and stratified bottom waters, sulfate acts as a terminal electron acceptor (TEA) and is reduced to sulfide during microbial respiration. Because dissolved sulfate concentrations are often low in continental surface water (as compared to marine systems), the biogeochemical significance of microbial sulfate reduction (MSR) in freshwaters is often underappreciated (e.g., Capone and Kiene 1988). However, considerable evidence has accumulated that even slightly elevated sulfate concentrations can greatly enhance MSR and cause a cascade of effects including the stoichiometric release of dissolved C, N, and P, the build-up of toxic concentrations of sulfide in sediment porewaters, and increased mobility and internal loading of P to surface waters (Myrbo et al. 2017b). MSR is also a primary process leading to the formation of bioaccumulative methylmercury (see below).

Although numerous studies have explored these various processes individually, their collective effects were recently revealed in a comprehensive mesocosm-scale experiment reported by Myrbo et al (2017b). Here the surface waters in a replicated series of large wetland enclosures (stock tanks in which wild rice was grown) were emended with five different sulfate treatments (control, 50, 100, 150, and 300 mg/L) and sampled (for sediments, porewaters and surface waters) after 3 and 5 growing seasons. The sulfate additions increased the mineralization of organic matter, thereby increasing surface water concentrations of dissolved and inorganic carbon, phosphorus, nitrogen, and total mercury in proportion to cumulative sulfate reduction. Mercury methylation was also enhanced by the sulfate addition, but peaked at intermediate treatment levels because of sulfide suppression of methylation in the highest sulfate treatment.

These results clearly demonstrate the potential for increased sulfate loading to significantly alter the biogeochemical environment of aquatic ecosystems through a cascade of primary and secondary environmental changes. Consequences include increased nutrient (N & P) availability and associated trophic changes, higher porewater sulfide with toxic effects on benthic communities and rooted aquatic plants, elevated biotic exposure to methylmercury, and increased alkalinity and dissolved organic carbon (DOC), keystone variables in the chemistry and physics of freshwater.

Mercury Methylation

Mercury (Hg) released to the atmosphere and surface waters from human activities is a serious environmental problem, because even trace amounts can bioaccumulate to harmful levels in fish and upper levels of the aquatic food chain. Inorganic mercury is transformed into its bioaccumulative form, methylmercury (MeHg), by anaerobic bacteria in the metabolic breakdown of organic matter in lake and wetland sediments and the bottom waters of thermally stratified lakes. Sulfate reducing bacteria (SRBs) are the most widely studied group of methylators, although other groups are known to possess the genetic and metabolic machinery needed to methylate (Gilmour et al. 1992, Hsu-Kim et al. 2013, Podar et al. 2015).

A number of key studies, both laboratory and field-based, have demonstrated conclusively that the experimental addition of sulfate to low-sulfate waters can stimulate SRB activity and increase the production of MeHg (Gilmour et al. 1992, Branfireun et al. 1999, Branfireun et al. 2001). At the same time, sulfide build-up in sulfate enriched systems can limit the bioavailability of inorganic mercury through the formation of charged mercury-sulfide species, thereby inhibiting methylation (Benoit et al. 2003, Hsu-Kim et al. 2013). These dual processes produce what is known as a “goldilocks” effect where sulfate is stimulatory at low concentrations and inhibitory at high concentrations. The optimal sulfate levels for methylation vary among systems, depending on the availability of other mercury ligands (particularly DOC), labile organic matter to drive microbial metabolism, and dissolved iron, which can precipitate sulfide and limit its negative feedback on bacterial uptake of inorganic mercury (Orem et al. 2014, Bailey et al. 2017, Pollman et al. 2017).

These complex interactions are well illustrated for northern Minnesota ecosystems by a series of studies that examined sulfate-mercury interactions in natural systems low in sulfate and contaminated waters with highly elevated sulfate concentrations. The first of these was a decade-long whole-ecosystem experiment where atmospheric sulfate inputs to a small boreal peatland were first increased and then decreased to explore the *in situ* response of net MeHg production and sulfur cycling. Results showed a dramatic rise in MeHg in both porewater and solid-phase peat as well as aquatic insects living in the experimental treatment (Jeremiason et al. 2006, Coleman Wasik et al. 2012). The cessation of experimental sulfate addition produced an initially rapid recovery that was also strongly modulated by hydrologic variation over the course of the experiment (Coleman Wasik et al. 2012, Coleman Wasik et al. 2015). The experimental sulfate increases were rather modest (4x ambient deposition) but produced a pronounced biogeochemical reorganization of the system including the bacterial community itself (Strickman et al. 2016).

A subsequent set of studies involving mining-impacted lakes and wetlands on Minnesota's Iron Range further illustrates the complexity of sulfate-mercury interactions (Bailey et al. 2017) (Johnson et al. 2016). In this case, study sites chronically impacted by sulfate discharges from iron mining (~200-300 mg/L) were compared with sites with moderate to background sulfate concentrations (5-30 mg/L). A strong and significant relationship was observed between porewater and solid-phase MeHg and sulfide concentrations <0.65 mg/L, but not at higher levels (sulfide > 0.65 mg/L) where methylation appeared to be suppressed by complexation of inorganic mercury with porewater sulfide (Bailey et al. 2017). In the most heavily sulfate-impacted sites, high sulfide contributed to the depletion of porewater iron in a feedback loop that

further limited the availability of inorganic mercury to bacterial uptake and methylation. Although high sulfide appeared to suppress the production of MeHg, it also contributed to its increased solubility in sediment porewaters, potentially enhancing transfer to the water column and biological uptake.

Unlike the Marcell wetland experiments, these comparative studies do not allow us to conclude what may have happened to methylation rates as mining-related sulfate discharges initially began to rise. It seems likely that they would have increased, even if additional sulfate loads eventually suppressed net MeHg production. Indeed, a biomonitoring study of mercury levels in dragonfly larvae from mining-impacted and non-impacted streams of the St. Louis River system do not show particularly elevated Hg in the sulfate impacted tributaries (Jeremiason et al. 2016). Although one might conclude from this that chronic sulfate enrichment had no deleterious effects on biotic exposure to MeHg, that would be incorrect, as pre-impact conditions are unknown for the sulfate-enriched tributaries and furthermore, many of the non-impacted ones drain extensive peatlands, which are known methylating environments (Wiener et al. 2006); wetlands are largely absent from mining-impacted sub-watersheds.

Wild Rice

Minnesota is unique among U.S. states and Canadian provinces in having a water quality standard that regulates dissolved sulfate to protect wild rice, *Zizania palustris* (Minnesota Rules 5050.0224). The standard is based on the long-standing empirical observation that wild rice is largely restricted in Minnesota to surface waters of less than 10 mg/L sulfate (Moyle 1944, 1945, DNR 2008). Although the standard has seldom been enforced, increasing public pressure to do so in the mining-impacted St. Louis River and a resurgent interest in developing metal-sulfide mining in northern Minnesota prompted the state to undertake a comprehensive re-evaluation of the standard to determine its appropriateness (MPCA 2015b). This 6-year investigation, only recently completed, used a combination of experimental and empirical approaches to better understand the mechanisms by which sulfate might affect the growth and survival of wild rice.

In a laboratory-based study wild rice germination and seedling growth were examined in hydroponic experiments that showed no direct effects of sulfate (under oxic condition) on seed germination or seedling development (Pastor et al. 2017). However, sulfide generated by sulfate reduction under anoxic conditions greatly reduced juvenile seedling growth at concentrations exceeding 320 µg/L. At the same time, outdoor mesocosm experiments – in which wild rice was grown in large containers containing lake sediment and standing water over 5 field seasons – showed progressive declines in seedling emergence, seedling survival, biomass growth, and seed production with sulfate additions over the course of the experiment (Pastor et al. 2017). Wild rice became largely extinct at sulfate concentrations of 250 mg/L or greater in the overlying water. These experimental results were corroborated by an extensive field survey of chemical and physical attributes of wild-rice habitat in more than 100 lake and river sites across Minnesota (Myrbo et al. 2017a). This field study demonstrated that sulfide in sediment porewaters, generated by microbial reduction of sulfate, is the primary control of wild rice.

A syntheses of these results using structural equation modeling (SEM) showed that pore-water sulfide could be accurately predicted by a combination of three key variables, surface water sulfate and the concentrations of organic carbon and amorphous iron in the sediments (Pollman

et al. 2017). The inferred mechanism is that both sulfate and organic matter stimulate microbial reduction of sulfate to sulfide, with iron serving to precipitate FeS in a feedback loop that limits the build-up of dissolved sulfide. The state of Minnesota is now weighing whether to retain the existing 10 mg/L sulfate standard or replace it with one that is based on site-specific measurement of the three controlling variables. The working conclusion of these studies is that the existing 10 mg/L standard may be over- or under-protective of certain waters, but that overall it is well justified based on the improved understanding of how sulfate affects wild rice growth and survival (MPCA 2015a).

These Minnesota studies demonstrate clearly the toxic nature of sediment sulfide to rooted aquatic plants like wild rice. Such toxicity was first identified in paddy-grown white rice (*Oryza sativa*) in the 1950s (Pearsall 1950), but has only recently been recognized as a critical control on the distribution abundance of plant and animal communities in freshwater ecosystems (Lamers et al. 2013). Increases in surface water sulfate have been implicated in declines of sawgrass (*Cladium jamaicense*) in the Florida Everglades (Li et al. 2009). The historical extirpation of wild rice from Minnesota lakes and streams receiving high sulfate drainage from iron mining activities is also suspected (Vogt 2012). Although wild rice may be particularly sensitive to sulfide toxicity, there is good reason to expect that other rooted aquatic macrophytes would be similarly impacted by elevated inputs of sulfate. Indeed, wetlands currently receiving high sulfate loads from iron mining activities (leakage or pumping from mine pits and tailings basins) have an extremely depauperate flora, largely dominated by cattails (*Typha* spp.), which are able to survive in sulfide-rich waters either by translocation of oxygen into their roots or metabolic detoxification of sulfide (Li et al. 2009, Lamers et al. 2013).

Implications for the BWCAW

The potential effects of sulfate release on the biogeochemistry of lakes and streams of the BWCAW and the Rainy River watershed depend on both the chemistry of the receiving waters and the magnitude of mining-related discharges. Although it is the position of mining interests that releases will not occur during active operations, there is substantial evidence that hydrological connections, either via groundwater or surface flow or from in-filling of existing mine pits will induce discharge from mine-impacted areas (mine pits, waste rock sites, processing basins) into nearby Birch Lake and the Kawishiwi River and thence into the heart of the BWCAW (Myers 2014, 2016a, b). Even if sulfate-impacted waters are contained during the period of active mining, perpetual treatment of drainage waters from abandoned mine operations will likely be needed following eventual mine-closure and site inactivation. Whether sufficient safeguards are ultimately put in place to ensure long-term protection of the Rainy River watershed is beyond the scope of these comments. However, it should be noted that sulfate-rich drainage from abandoned iron-mining operations currently discharge into Birch Lake, raising sulfate and trace-metal levels in the receiving waters (USEPA 1994). The full biogeochemical consequences of this historical contamination are presently unknown.

Surface waters of the BWCAW are likely to be among the most sensitive to elevated sulfate inputs of those in any of Minnesota's major watersheds. Located on crystalline bedrock of the Canadian Shield, most lakes and streams are ionically dilute, of circumneutral pH, and high in dissolved organic carbon (DOC). The MPCA's water quality database, EQuIS, contains some 7000 records of surface-water sulfate from Lake and St. Louis counties. Within this data set,

lakes and streams not impacted by existing iron-mining operations are invariably quite low in sulfate (3.3 ± 1.8 mg/L; mean $\pm$ s.d.; $n = 2960$). The Kawishiwi River is only slightly higher (5.7 ± 2.8 , $n = 108$), while Birch Lake is significantly elevated (9.5 ± 3.4 , $n = 75$), presumably owing to leakage from waste rock at the nearby Dunka mine site. At these ambient levels, it is highly likely that an increase in sulfate loading will cause an increase in microbial sulfate reduction (MSR) and associated mercury methylation. That is, these waters are on the lower (rising) limb of the “goldilocks curve” under which sulfate will stimulate net methylation of mercury, rather than inhibit it. If sulfate discharges to the system are sufficiently large (c.f. the mining-impacted St. Louis River), sulfate contamination will progress downstream. Sulfate will be consumed through MSR in upstream lakes and a zone of enhanced methylation (goldilocks peak) will migrated downstream. Finally, there are abundant wetlands in the Birch Lake watershed near proposed sulfide-metal mining operations (e.g. Filson and Kelley creeks) (Geerts 2017), as well as further downstream, and boreal wetlands are known to be especially effective methylating environments (Wiener et al. 2006). Lakes and streams of the Rainy River watershed also support abundant and diverse plant communities, including wild rice, which are almost certain to be impacted by elevated inputs of sulfate from mining operations. Finally, the biogeochemical release of nutrients (P and N) from enhanced MSR could lead to increased algal production in surface waters and a wholesale change in trophic conditions in what are otherwise among the most pristine waters of the U.S.

The BWCAW is classified as “outstanding resource value water” under the Minnesota statutes (MAR 7050.0180), whereby: “The agency [MPCA] recognizes that the maintenance of existing high quality in some waters of outstanding resource value to the state is essential to their function as exceptional recreational, cultural, aesthetic, or scientific resources. To preserve the value of these special waters, the agency will prohibit or stringently control new or expanded discharges from either point or nonpoint sources to outstanding resource value waters.” (MAR 7050.0180 Subpart 1). Given the abundant evidence, summarized above, that sulfate releases from mining operations through the Kawishiwi watershed and into the BWCAW pose substantial environmental risk to these outstanding resource value waters, it is scientifically prudent that mining leases held by Twin Metals and other mining interests be withdrawn by the Secretary of the Interior for a 20-year term as requested by the US Forest Service.

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TECHNICAL DOCUMENT

ACID MINE DRAINAGE PREDICTION

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discharge and water from the impoundment, seepage return pond, and pump back system is returned to the mill, the TSP application were expected to cause elevated phosphorus levels in the reclaim water. Cyprus personnel indicated these levels may adversely affect flotation operations and that this issue was being studied.

Cyprus' original plan for reclamation of the tailings impoundment indicates that Cyprus initially anticipated that water quality standards could be met by diluting impoundment seepage with natural runoff. No water treatment beyond sediment control was expected to be required. However, the original reclamation plan did not consider the AMD issue. According to Cyprus personnel, the AMD problem could extend well beyond the life of the mine and perpetual care/treatment may be necessary. Therefore, Cyprus was evaluating remedial alternatives (other than perpetual care) and was preparing to submit a revised tailings pond reclamation plan (as a modification to their operating plan).

Alternatives to be considered included installing an additional flotation unit to remove pyrite and/or in-place treatment of tailings with trisodium phosphate as a buffer. Preliminary flotation tests have been conducted to investigate the possibility of removing sulfides from the tailings prior to disposal in the impoundment. Test results indicated that a high percentage of pyrite may be recovered. Limited static testing performed on a whole tailings sample from which pyrite was recovered indicated a NP/AP ratio in excess of 4:1 compared to an average value of 0.84:1 for all tailings analyses.

According to Cyprus personnel, oxidation had only been found to occur in the top two to three feet of tailings (despite the results of analyses of the 1990 borehole samples that showed oxidation at all depths down to 150 feet). Therefore, an additional alternative under consideration was to encapsulate the tailings. Information on specific types of cover materials was not provided. Additionally, Cyprus was investigating the potential use of wetlands treatment.

3.3 LTV Steel Mining Company, The Dunka Site, Minnesota

3.3.1 Introduction

EPA visited the LTV's Dunka site in August 1991 (U.S. EPA 1992d). The site is located approximately 20 miles northeast of LTV Steel Mining Company's (LTV SMCo.) Hoyt Lakes facility. The site is on private, State, Bureau of Land Management, and U.S. Forest Service lands; LTV SMCo. holds surface and mineral leases for the area. The Dunka pit is part of the eastern-most extension of the Biwabik iron formation and is one of the smaller pits on the Mesabi Range at three miles in length. Although additional material may be removed from the pit for beneficiation, in 1991, plans called for no further exploration activity at the site or enlargement of the pit.

3.3.2 The Acid-Generating Duluth Complex

The taconite ore at the Dunka site contacts Duluth Complex material (DCM), which must be removed to reach portions of the taconite ore deposit. The Duluth Complex is a sulfur-containing, mafic intrusive rock unit, considered to be one of the largest known sources of copper and nickel resources. As of late 1991, LTV SMC Co. had removed and placed in "gabbro" stockpiles approximately 50 million tons of Duluth Complex material containing an average of more than 0.2 mass percent copper oxides and/or 0.05 mass percent nickel oxides as gabbro stockpiles.

The remaining Duluth Complex material stockpiles were categorized as waste rock stockpiles and are made up of material containing less than 0.2 percent copper oxide and less than 0.05 percent nickel. Since these waste rock stockpiles were constructed in 1976, monitoring of drainage from the piles has revealed a decrease in pH levels, as well as an increase in trace metal concentrations. Copper and nickel concentrations as high as 1.7 and 40 mg/L, respectively, were observed in seepage/runoff from Duluth Complex waste rock stockpiles at the site. In addition, during sampling conducted by the Minnesota Department of Natural Resources between 1976 and 1980, pH values as low as 5.0 at Seep 1 were reported.

3.3.3 Acid Rock Drainage Prediction Methods

To address this drainage, the Minnesota Department of Natural Resources in conjunction with LTV SMC Co., constructed full scale test piles of the Duluth Complex material to monitor its acid generation potential. The MDNR continues to monitor the test piles and study acid generation. Lapakko (1988) conducted kinetic tests of Duluth Complex material using a humidity cell. Nine samples were selected from core material and one sample from a test stockpile. This experimental method was selected based on ongoing field test results, which demonstrated a strong correlation between sulfur content, trace metal mobility, and acid production. Laboratory scale tests provided better control and simplified analysis. Sulfur content was identified as the independent variable. Samples that had variable sulfur content were selected. Part of the study was to determine the feasibility of extrapolating laboratory results to operational conditions.

Each cell was loaded with 75 gram rock samples passing 100 mesh but less than 270 mesh. Samples were rinsed with 200 ml of distilled-deionized water, which was allowed to remain in contact with the sample for five minutes. Rinse water was collected and filtered through a 45 micron filter. At the beginning of the experiment, the samples were rinsed five times to remove oxidation products generated during sample preparation. Two rinses were used each week during the remainder of the experiment. Between the weekly rinsings, the samples were stored in a box fitted with temperature and humidity controls.

The laboratory study found that drainage pH decreased as the sulfur content of the sample increased. Drainage pH also decreased as the experiment time increased. Both of these findings are consistent with field observations on pH variation correlated with sulfur content and time. Based on the data, Lapakko (1988) concluded that the small particles (<2.0 mm) have a large influence on field stockpile drainage quality. The weighted average sulfur content for particles in this fraction is 1 percent compared to 0.6 percent in the bulk

rock. Most of the sulfur occurs as pyrrhotite. The higher sulfur content combined with the higher surface area of these particles make this fraction susceptible to more intense oxidation reactions.

3.3.4 Environmental Risks

Toxicity testing of the leachate showed that copper and nickel concentrations exceeded the 48-hour lethal concentration (LC50) for *Daphnia pulicaria*; nickel concentrations also exceeded the 96-hour LC50 for fathead minnow. Concentrations of calcium, magnesium, and sulfate in the stockpile drainage were also elevated. According to LTV SMC., there was some question whether the metals were the toxic agent.

Most of the seepage from waste rock piles at the Dunka site has historically been discharged to Unnamed Creek. Unnamed Creek flows into Bob Bay, a part of Birch Lake. In a 1976-1977 study of trace metals in Bob Bay, it was found that concentrations of copper, nickel, cobalt, and zinc in the waters of the Bay were higher than the regional average concentrations and decreased with distance from the mouth of Unnamed Creek. Elevated metal concentrations were also observed in the sediments, as well as in aquatic plant and clam tissue. In the study, it was estimated that the total discharge from the Dunka watershed into Bob Bay through Unnamed Creek was 500 million gallons per year. Unnamed Creek contributes more than 90 percent of the trace metals load to Bob's Bay. Annual loading is over one ton of nickel. Less than 40 percent of this nickel load was found to be removed from the system through natural lake processes. According to LTV SMC., carbon dating of sediment samples from Bob Bay indicates significant metal concentrations which predate mining.

3.3.5 Treatment

As of late 1991, the State and LTV SMC. were working to develop technologies to mitigate leachate generation and release of trace metals associated with stockpile drainage. The technologies being tested and employed included pile capping/channeling to limit infiltration, active treatment in a neutralization pond to lower pH and remove metals, and use of artificial wetlands to remove metals. The ultimate goal was a passive treatment system that would require little or no maintenance (U.S. EPA 1992d).

3.4 California Gulch

The California Gulch NPL site is located in the upper Arkansas River Valley in Lake County, Colorado. It is bounded by the Arkansas River to the west and the Mosquito Mountains to the east, and is approximately 100 miles southwest of Denver. The study area for the remedial action encompasses approximately 15 square miles, and includes California Gulch and the City of Leadville. California Gulch is a tributary of the Arkansas River. Mining for lead, zinc, and gold has occurred in the area since the late 1800's. This site was added to the NPL in 1983 (U.S. EPA, 1991).

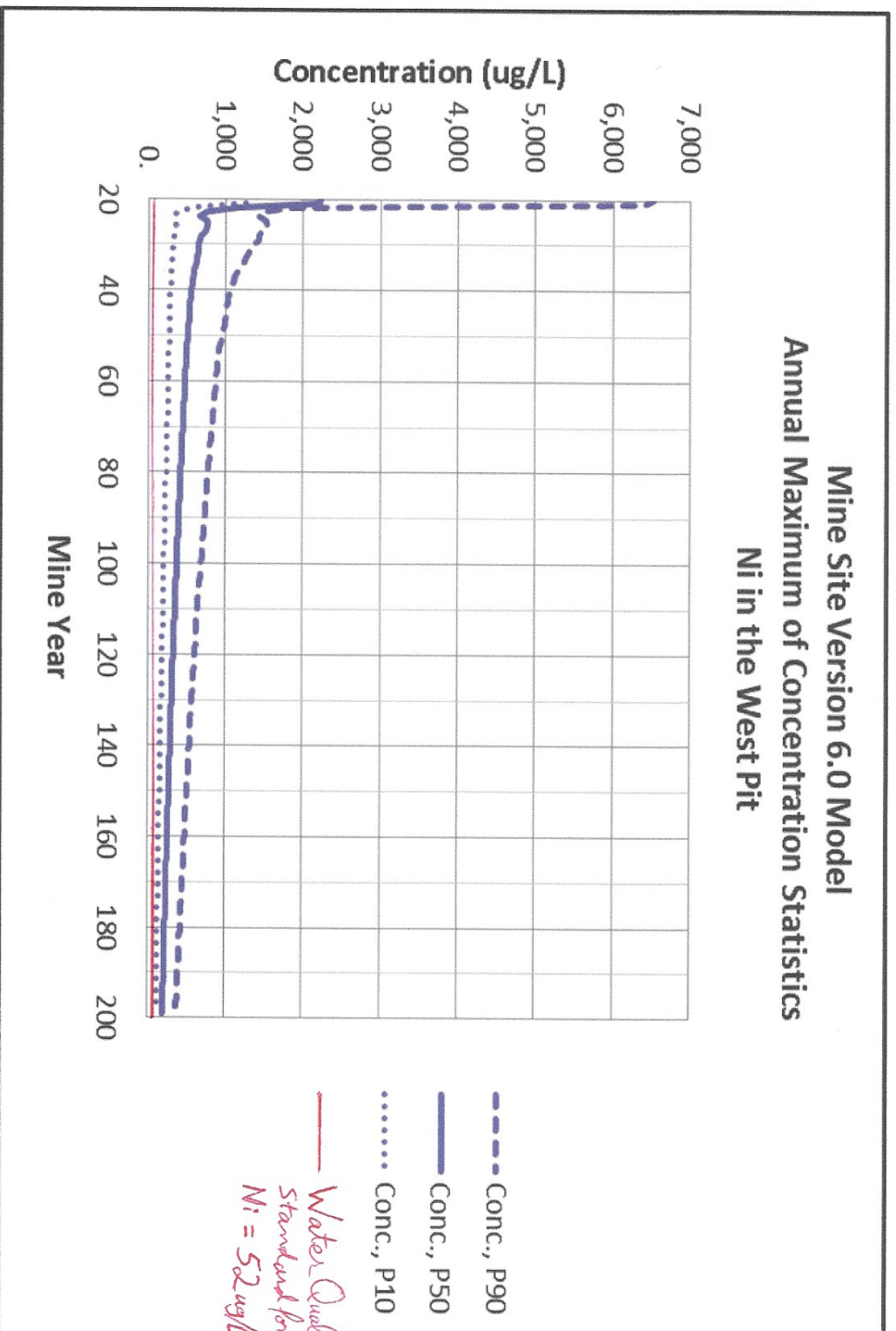
A Remedial Investigation conducted by EPA in 1984 indicated that the area is contaminated with metals (including cadmium, copper, lead, and zinc migrating from numerous abandoned and active mining

**Water Quality Modeling Results for
Nickel (Ni) and Sulfate (SO₄) at
Mine Site West Pit, Northmet
(PolyMet) Project**

**Final EIS
2015**

**A Sulfide-Ore Copper/Nickel Mine
Proposed to be Developed in the
Duluth Complex of Minnesota**

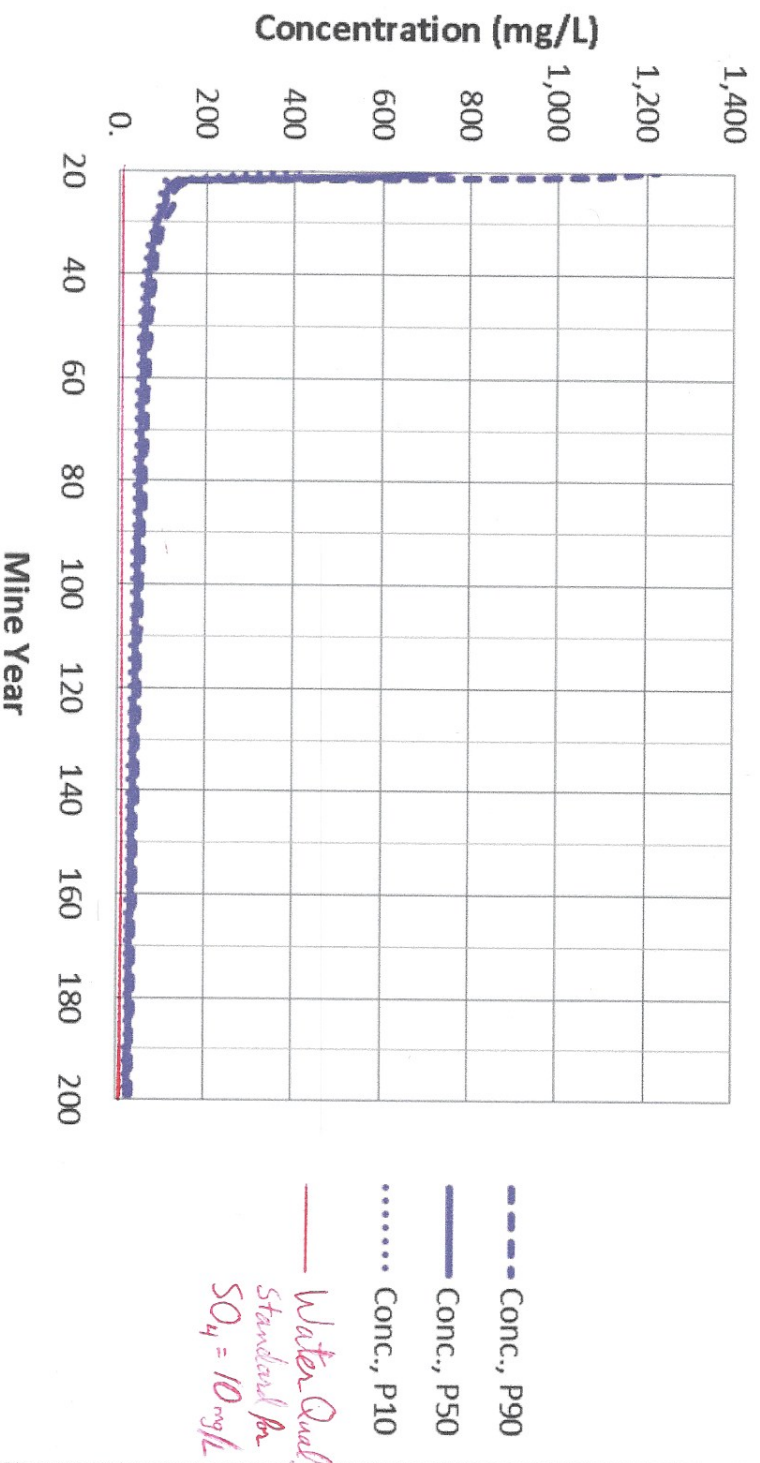
**Mitigation will be required for at
least 200 years at the Mine Site and
500 years at the Processing Site**



Source: PolyMet 2014v.

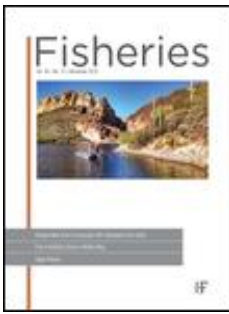
Figure 5.2.2-42 **Nickel Concentration in the West Pit during Reclamation, Closure, and Post-Closure Maintenance**

Mine Site Version 6.0 Model Annual Maximum of Concentration Statistics SO₄ in the West Pit



Source: PolyMet 2014v.

Figure 5.2.2-43 *Sulfate Concentration in the West Pit during Reclamation, Closure, and Post-Closure Maintenance*



AFS Position Paper and Policy on Mining and Fossil Fuel Extraction

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AFS Position Paper and Policy on Mining and Fossil Fuel Extraction

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Following a four-year period of writing, member comment, and multiple revisions, the AFS Position Paper and Policy on Mining and Fossil Fuel Extraction was approved unanimously by the membership at the Society's annual business meeting August 19, 2015, in Portland, Oregon. The entire document can be read at fisheries.org/policy_statements; a brief summary follows.

TECHNICAL BACKGROUND

Mining (hard-rock, aggregate, deep, and surface) and fossil fuel (coal, oil, gas) extraction have the potential to significantly alter aquatic ecosystem structure and function. Adverse impacts on water quality, hydrology, physical habitat structure, aquatic biota, and fisheries include elimination and contamination of receiving waters (USEPA 2011; USEPA 2014); significantly altered algal, macroinvertebrate, and fish assemblages (e.g., Pond et al. 2008; Lavoie et al. 2012; Daniel et al. 2014; Figure 1); impairments of aquatic-dependent wildlife (USEPA 2011; USEPA 2014); and climate change (Hansen et al. 2013).

For example, even at low concentrations, mining-associated contaminants, such as copper, impair salmonid olfactory function (McIntyre et al. 2008), thereby increasing predation susceptibility (McIntyre et al. 2012); alter salmonid migratory behavior (Sprague et al. 1965; Lorz and McPherson 1976); increase disease susceptibility (Baker et al. 1983); and reduce growth (Marr et al. 1996).

Despite predicted compliance of permit conditions, many operating metal mines have violated water quality criteria (Kuipers et al. 2006). Those permit conditions, or applicable regulations, are minimum requirements and typically do not represent best management practices. Also, the applicable regulations rarely account for the cumulative effects of pollution from multiple mines.

Under the General Mining Act of 1872 in the United States, federal law transfers metal wealth from the public to mining companies, and shifts clean-up liability from those companies to taxpayers. The half-million abandoned hard-rock mines in the United States could cost US\$72-240 billion to rehabilitate (USEPA 2000; NRC 2005), and the over 100 abandoned metal mines in Quebec are estimated to cost over US\$600 million to remediate (Hamilton et al. 2015). In both cases, the majority of those costs will fall on taxpayers (Woody et al. 2010; Chambers et al. 2012; Hamilton et al. 2015). In addition, those estimates do not include rehabilitation of the newer, larger mines being

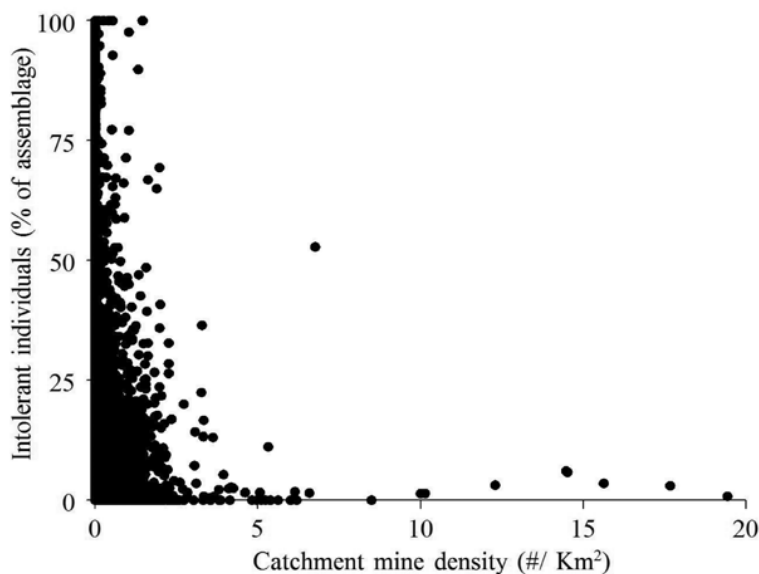


Figure 1. Percent generally intolerant fish individuals as a function of mine density for the conterminous USA ($n = 33,538$). Mines include coal, hard rock, uranium, and aggregate mines.

developed in more inhospitable environments, nor the costs of spills, failures, and accidents. Such a spill into the Animas River occurred on August 5, 2015, when U.S. Environmental Protection Agency contractors were assessing leaks of toxic metals in the vicinity of the abandoned Red, Bonita, and Gold King mines near Silverton, Colorado, and broke the debris dam of a holding pond (Vox 2015). That spill sent 12 million liters of contaminated water downstream and into the states of New Mexico and Utah via the San Juan River; the costs of fish kills, water monitoring, clean-up, and loss of water use by recreationalists, irrigators, and other users have been estimated in the tens of millions of dollars. The Mt. Polley tailings pond failure on August 4, 2014, which spilled 14 million m³ of metals-contaminated water and sediments into Hazeltine Creek and Polley and Quesnel Lakes in central British Columbia, has been estimated to cost at least \$500 million (US) to rehabilitate (Uechi 2014). Because of various economic factors, the numbers of serious and very serious tailings dam failures such as these have increased since 1960 (Bowker and Chambers 2015).

Surface mining temporarily eliminates surface vegetation and permanently changes topography and hydrology, as with mountain-top-removal-valley-fill (MTRVF) coal mines (Fritz et al. 2010; USEPA 2011). Reclaimed surface mines create a leach bed for ions producing toxic conductivity concentrations (Pond et al. 2008), whereas altered hydrology produces flashy flows similar to those in urban areas (Ferrari et al. 2009; USEPA 2011). Underground mines produce acid mine drainage that can eliminate most aquatic life across extensive regions or alkaline mine drainage that alters ionic balance of freshwater ecosystems (USEPA 1995; USEPA 2000). Instream and gravel bar aggregate mining and dredging can alter channel morphology and increase bed and bank erosion, which can reduce riparian vegetation and impair downstream aquatic habitats (Kondolf 1994).

Oil and gas wells and product transport can cause devastating spills in freshwater and marine ecosystems (e.g., AP 2012; Amezcua-Linares 2013; Keller 2015). Hydraulic fracturing to extract residual oil and gas can contaminate

groundwater and alter surface water ecosystems (Entrekin et al. 2011; Weltman-Fahs and Taylor 2013). Fish biodiversity and macroinvertebrate taxa richness were negatively correlated with the number of well pads per catchment and total mercury concentrations in crayfish, and Brook Trout *Salvelinus fontinalis* were positively correlated with well pads per catchment (Grant et al. 2015). Smith et al. (2012) concluded that fewer than one well pad per 3 km² and 3 ha per pad were needed to minimize damage to Brook Trout populations. Bamberger and Oswald (2012) and Webb et al. (2014) documented a wide range of health effects as a result of exposure to fracking fluids and gases. McKenzie et al. (2012) reported cumulative cancer risks of 10 per million for residents living <800 m from a gas well. Stacey et al. (2015) and Cil (2015) associated lowered infant health with proximity of drinking water wells to gas wells. The casings and grouting of abandoned oil and gas wells should be expected to eventually leak and contaminate surface and ground water (Dusseault et al. 2000). In addition, fossil fuel combustion is fundamentally altering the global climate, sea levels, and ocean chemistry (e.g., Orr et al. 2005; Dai 2013; Hansen et al. 2013).

Catastrophic mine tailings failures have killed hundreds of thousands of fish and hundreds of people, and contaminated tens to thousands of river kilometers (USEPA 1995; Chambers and Higman 2011; WISE 2011). Oil and gas wells are exempted from regulation by several U.S. laws, despite considerable evidence of their detrimental effects on surface and ground water (Allen et al. 2011; Amezcua-Linares 2013; Keller 2015).

PROPOSED AFS POLICY

Mines and wells should only be developed where, after weighing multiple costs, benefits, beneficiaries, and liabilities, they are considered the most appropriate use of land and water by affected publics, can be developed in an environmentally responsible manner, benefit workers and affected communities, and are appropriately regulated. Because of substantial widespread adverse effects of mining and wells on aquatic ecosystems and related human communities, fossil fuel

combustion effects on global climate, and enormous unfunded reclamation costs for abandoned extraction sites, the American Fisheries Society (AFS) recommends substantive changes in how North American governments conduct environmental assessments and permit, monitor, and regulate mine and fossil fuel development. In particular, AFS recommends that:

1. Following a formal environmental impact assessment, the affected public should be involved in deciding whether a mine or well is the most appropriate use of land and water, particularly relative to the need to preserve ecologically and culturally significant areas.
2. Mine or well development should be environmentally responsible with regulation, treatment, monitoring, and sureties sufficient for protecting the environment in perpetuity.
3. Baseline ecological and environmental research and monitoring should be conducted in areas slated for mining and fossil fuel extraction before, during, and after development so that the effects of those industries can be assessed in an ecologically and statistically rigorous manner, and the resulting data should be made publicly available.
4. This policy and related research should help inform the process of responsible resource development for mining and fossil fuel extraction, and should guide the implementation of the precautionary principle for those sectors.
5. A formal risk assessment of the cumulative atmospheric, aquatic, and oceanic effects of continued fossil fuel extraction and combustion should be conducted and reported to the public.
6. A formal risk assessment of the cumulative aquatic and oceanic effects of continued hard rock and aggregate extraction and metals smelting should be conducted and reported to the public.

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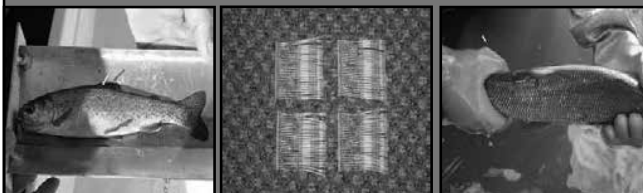
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Recently-Published Peer-Reviewed Science
Sulfate (SO₄) and its Effects on Water Quality and Aquatic Vegetation
Minnesota Pollution Control Agency Research
December 2017

Research sponsored by the Minnesota Pollution Control Agency (MPCA) has generated a series of peer-reviewed, published scientific papers that document the relationships between sulfate, sulfide, iron, organic carbon, and wild rice; sulfate and methyl-mercury formation; and sulfate and eutrophication. The papers, cited below, are available for free download at the journals' websites.

The first, third, and fourth papers explain the chemical processes by which the addition of sulfate to low-sulfate waters, like those in the Boundary Waters Canoe Area Wilderness and Superior National Forest, and the reduction of sulfate to sulfide – a process mediated by organic carbon and iron – is particularly damaging to wild rice (and other aquatic plants) and can lead to diminution and elimination of plants from waters where they now grow. The second paper explains how addition of sulfate to surface water leads to increased surface water concentrations of phosphorus, nitrogen, mercury and methylmercury.

Studies:

Myrbo, A., E.B. Swain, D.R. Engstrom, J. Coleman Wasik, J. Brenner, M. Dykhuizen Shore, E.B. Peters, and G. Blaha. 2017. Sulfide generated by sulfate reduction is a primary controller of the occurrence of wild rice (*Zizania palustris*) in shallow aquatic ecosystems. *Journal of Geophysical Research: Biogeosciences*.

Available at: <http://onlinelibrary.wiley.com/doi/10.1002/2017JG003787/epdf>

Myrbo, A., E.B. Swain, N.W. Johnson, D.R. Engstrom, J. Pastor, B. Dewey, P. Monson, J. Brenner, M. Dykhuizen Shore, and E.B. Peters. 2017. Increase in nutrients, mercury, and methylmercury as a consequence of elevated sulfate reduction to sulfide in experimental wetland mesocosms. *Journal of Geophysical Research: Biogeosciences*.

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Predicting Water Quality at Hardrock Mines

**Methods and Models, Uncertainties, and
State-of-the-Art**



**Buka
Environmental**



**Kuipers &
Associates**

Predicting Water Quality at Hardrock Mines

Methods and Models, Uncertainties, and State-of-the-Art

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Front cover: Left – Partially filled open pit at the Equity Silver Mine (silver) in British Columbia, Canada. Center – Open pit at the Bingham Canyon Mine (copper) in Utah USA. Right – Two-year kinetic tests at the Montana Tunnels Mine (gold, silver, lead, zinc) in Montana USA. Back cover: Construction of the heap leach pad at the Marigold Mine (gold) in Nevada USA. All Photos by Ann Maest.

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FOREWORD

The prediction of water quality at mine sites, the focus of this report, is a challenging topic because of its technical complication and inherent uncertainties. The quantity and characteristics of mine wastes are among the most important determinants of water quality at a mine site. Mine wastes or mined materials include the extraction area (open pit or underground mine), waste rock, unprocessed lean ore, heap or dump leach piles, tailings, and metallurgical processing wastes, although all of these wastes may not be present at a specific operation. The quantity of material generated can be very large, with mine waste areas covering hundreds of acres and amassing to tens or hundreds of million tons. The quality of mine waste drainage can be environmentally innocuous, circumneutral to basic with elevated concentrations of metals and oxyanions, or highly acidic with very high heavy metal concentrations. In addition to the potentially large physical size of mine waste disposal facilities, these materials remain on the ground long after mining and processing operations cease and can generate problematic drainage for centuries. Thus, in the absence of remediation, mine wastes are potentially sources of contaminants that may be transported from the mine site and adversely impact environmental or human receptors for many years.

Mine waste characterization techniques, in conjunction with geochemical and physical modeling and relevant existing data, have been applied to predict the quality of drainage that will be generated by mine wastes over time. These predictions are intended to contribute substantially to the fundamental information required to design and cost remediation that will allow compliance with water quality standards in a technically and economically efficient manner. Designing remediation measures in advance of mining allows their costs to be factored into the economics of mineral resource recovery, and for environmental mine waste management measures to be integrated effectively into the mine plan. Whereas this concept is fairly simple, the prediction of mine waste drainage quality over time can be a difficult proposition.

Factors that complicate drainage quality prediction range in scale from small to large. First, on a small scale, drainage quality is influenced by the dissolution of minerals present in the mine wastes, as well as secondary reactions among solutes, gas phases, and

solid surfaces. The mineral surface areas available for reaction can be difficult to quantify, and the rates of reaction in a complex system are not well known. Second, on the large scale, geology, climate, methods of mining and mineral processing, and mine waste management approaches vary among and within operations. Variability of these large-scale factors means that characterization problems and results can be unique to an operation or operational component, and this limits the degree to which information from one site can be applied to another. Third, extrapolation from laboratory to operational scale must address complicating factors such as differences in particle size, environmental conditions, water and gas transport, and how these variables affect drainage quality over periods of decades or centuries. There is virtually no available information describing the effect of variables such as these on well characterized operational mine wastes over extended periods of time. The lack of this field information introduces uncertainty into predictions, and this uncertainty must be accounted for. Finally, characterization results and subsequent modeling must lead to environmental mine waste management programs that are practical and verifiable in the field. Given the large masses of material often moved in mining operations, this consideration is far from trivial.

Despite these difficulties, geochemical characterization techniques can provide predictive information on mine waste drainage quality that is beneficial to the environmentally sound management of mine wastes. Given the complexity of long-term predictions and the associated uncertainty, mine waste characterization should be viewed in the context of a program, integrating results from a variety of characterization techniques over time, rather than a single test or a one-time series of tests. This program begins with testing in the exploration phase and extends through closure and post-closure in the form of monitoring. Technical expertise from those experienced in the field will most likely be required to develop and apply a well-designed waste characterization program.

This report identifies various techniques for the geochemical characterization of mine wastes, including conventional geochemical and mineralogical analyses, static tests, short-term dissolution tests, and

kinetic tests. For each technique, the report addresses advantages and limitations and sources of uncertainty, and makes concise recommendations for improvements. Sources of uncertainty in characterization and modeling identified in this report can be used to evaluate mine characterization and management plans. The characterization flow chart presented in the report provides a strategy that can be used at a wide variety of mine sites and recognizes that the specific characterization techniques can vary among these sites. Collection of an adequate suite of samples for testing is also discussed, and is a cornerstone for a reliable characterization program.

The application of characterization techniques during various phases of mineral resource development (exploration, development, active mining, and reclamation, closure, and post-closure) is discussed in this report. A modeling approach including development of a conceptual model, input data collection (including characterization results), model selection, sensitivity analysis, and evaluation of results is presented. The information presented in this report addresses many of the challenges associated with predicting water quality at mine sites noted above and will be useful to regulators, mine operators, and the public who are involved in mine waste characterization and modeling projects.

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August 2005

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LIST OF ACROYNMS

1D, 2D, 3D	1, 2, 3 dimensional
µg/L	microgram/liter
µm	micrometers
AAS	atomic absorption spectrometer
ABA	acid base accounting
ACMER	Australian Center for Minerals Extension and Research
ADTI	Acid Drainage Technology Initiative
AG	acid generating
AGP	acid generation potential
AMD	acid mine drainage
AP	acid production potential
ARD	acid rock drainage
AVIRIS	Airborne Visual and Infra-Red Imaging Spectrometer
BCRC	British Columbia Research Confirmation test
BCRI	British Columbia Research Initial test
BC SWEP	British Columbia special waste extraction procedure and modification
°C	degrees Celsius
cm	centimeter
DI	deionized water
EP Toxicity	extraction procedure toxicity test
eq/t	equivalents of calcium carbonate per ton
gm	gram
HCT	humidity cell test
hr	hour
ICMM	International Council on Mining and Metals
ICP-MS	Inductively-coupled plasma – mass spectrometer
IGWMC	International Groundwater Modeling Center
INAP	International Network for Acid Prevention
K _d	distribution coefficient
kg	kilogram
L	liter
m	meter
M	molar
MEP	multiple extraction procedure
MEND	Mine Environmental Neutral Drainage
min	minute
mL	milliliter
mm	millimeter
MWMP	meteoric water mobility procedure
N	normal
NAA	neutron activation analysis
NAG	net acid generating test
NCV	net carbonate value test
NEPA	National Environmental Policy Act
NP	neutralization potential
NPL	National Priorities List
NRC	National Research Council
OD	outside diameter
P	pressure
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control

RCRA	Resource Conservation and Recovery Act
SC	specific conductance
SEM/EDS	scanning electron microscopy/energy dispersive system
SME	Society of Mining, Metallurgy, and Exploration
SPLP	synthetic precipitation leaching procedure
T	temperature
TCLP	toxicity characteristic leaching procedure
TIC	total inorganic carbon
UNEP	United Nations Environmental Programme
USACOE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOC	volatile organic compound
WET	California waste extraction test
WWG	World Wide Acid Rock Drainage Guide
XRD	X-ray diffraction
XRF	X-ray fluorescence

OVERVIEW

In order to determine if a given hardrock mine project will be protective of water resources during and after mining, regulators at state and federal agencies review Environmental Impact Statements or other types of environmental assessment documents submitted by mine proponents. In these assessments, the potential of the mined materials to generate acid and contaminants and to affect water resources is evaluated using a number of laboratory and field techniques and a variety of predictive modeling approaches. The regulator's job is to evaluate, sometimes with incomplete information, whether the tests and modeling that were conducted were appropriate for the site-specific conditions at the mine and whether the predictions and the mining approach are reliable enough to guarantee that future environmental liability is adequately addressed.

According to the U.S. EPA's Abandoned Mine Land Team, the cost of remediating mine sites on the National Priorities List (NPL) in the United States is on the order of \$20 billion. Recent increases in the prices of precious and base metals on the world market have triggered an increase in the number of new mines being proposed in the United States and around the world. In the United States alone there are on the order of 170 large hardrock mines – in nearly all regions of the country – that are in various stages of being proposed, in permitting, in construction, operating, or recently closed and require oversight and ongoing evaluations by state and federal agencies. In order to reduce liability costs associated with hardrock mining, improvements must be made in mine evaluations before mining begins and also throughout the life of the mine. This report lays out a framework for evaluating the methods and models used to predict water quality at hardrock mine sites and makes recommendations for their improvement. It is intended to be used by regulators, the interested public, and mine operators and managers.

The companion study to this report, *Comparison of Predicted and Actual Water Quality at Hardrock Mines: The reliability of predictions in Environmental Impact Statements* (Kuipers et al., 2005), reviews predictions made in Environmental Impacts Statement for large hardrock mines in the United States – predictions based in part on characterization and modeling approaches – and evaluates their reliability using operational water quality data. Findings from

that study highlight the importance of obtaining characterization data through all stages of mining and using this information in forecasts of mine site water quality.

Although predictive modeling is by its nature uncertain, it is valuable for helping to describe and understand the physical, chemical, and biological changes that can occur to natural systems from mining activity. Much of the uncertainty related to predicting water quality at mine sites derives from inadequate or inaccurate conceptual models, hydrologic and geochemical characterization data, and input data to hydrogeochemical models.

The creation of a site conceptual model is an important first step in predicting water quality at mine sites. In order to create a useful conceptual model, baseline hydrogeologic and geochemical data from the proposed mine must be collected and interpreted. The pathways through which contaminants can travel from mine sources to receptors should be identified and characterized, and the effects of any proposed mitigation measures on contaminant transport should be estimated. Conceptual models are not unique and can change over time as mining progresses. Therefore, it is necessary to revisit conceptual models and modify mining plans and predictive models based on new site-specific information.

One of the biggest challenges in predicting water quality is estimating the long-term geochemical behavior of mined materials. Unlike other industrial facilities, contaminant discharges from mine sites can take years, decades, or longer to develop and are subject to climatic and seasonal variability in concentrations and flow. Laboratory and field geochemical testing and careful measurements of hydrologic and meteorologic conditions at the site over time are needed for improved water-quality predictions. Mineralogic characterization is an underutilized tool in the prediction of the geochemical behavior of mined materials. Static tests and short-term leach tests are not designed to simulate long-term behavior of mined materials. Properly conducted static tests can instead provide estimates of the total amount of acid-generating and -neutralizing material present, and short-term leach tests can be used to simulate the short-term interaction of water with weathered, mined materials. Results from static tests can be useful as an

initial screening method to determine which materials should be examined further for acid-generation potential but should not be used to predict the long-term ability of mined materials to generate acid. Similarly, results from short-term leach tests may be useful for estimating leachate concentrations in, for example, waste rock runoff after a storm event but should not be used to predict concentrations of leachate in seeps whose waters derive from slower pathways within the pile. Kinetic tests are designed to estimate longer-term geochemical behavior of mined materials. However, there are a number of issues, mostly related to particle size and length of the tests that can cause kinetic tests to be poor predictors of long-term water quality. These issues require that kinetic testing start as early as possible in the development of a proposed mine, and that the results be reported in terms of available surface area of minerals that control acid generation, acid neutralization, and contaminant leaching. Involvement of a person with in-depth understanding and experience in mine waste characterization approaches and interpretation will help prevent misinterpretation of characterization test results and result in a well-designed and applied waste characterization program.

At mine sites, much of the modeling performed is “forward” modeling, or modeling of conditions that do not yet exist. In the case of pit lakes, steady-state water quality and quantity conditions may not exist for hundreds of years, yet predictions about the quality of pit water are often requested for regulatory purposes. The difficulty in checking modeling results against actual water quality results in large uncertainties in the accuracy of predictive water quality modeling. Most of the other uncertainties in predictive modeling at mine sites relate to values used as inputs to the models rather than to the validity of the model itself. The model or models chosen to predict water quality should be representative of the site (as reflected in the site conceptual model) and be applied at a level of complexity that is appropriate for the available data and the regulatory decisions that must be made. In many cases, available data may limit the model application, and it may be more appropriate to develop a less-complex, screening-level model when data are not available to support a more complex model. For mines that are already developed, field sampling will provide the best measure of water quality. Site-specific values used as inputs to models must be as accurate of the range of conditions at a mine site as possible and should consider seasonal and other types of temporal variability.

The inherent uncertainty in model predictions is rarely stated or recognized. Methods used to evaluate or account for model uncertainty include Monte Carlo analysis, other stochastic methods, and evaluating a range of model input values to develop a range of outcomes (e.g., a range of water quality in a given receptor). These methods account for the fact that, rather than being well described by a single value as required in the model, parameters are better described with a probability distribution. However, uncertainty evaluation of parameter input will not address inaccuracies in conceptual models. Presenting potential contaminant concentrations at receptors as ranges rather than absolute values will better reflect the uncertainty inherent in predictive modeling.

Hydrologic and geochemical codes still solve the same basic equations and reactions that were identified 80 or more years ago. Some of the most notable improvements in both hydrologic and geochemical codes are the operating systems and the graphic interfaces, which allow more user-friendly operation of the codes and better visual output of the modeling results. Individual codes have slight advantages and disadvantages, depending on the application, but the experience of the modeler, the choice of input parameters and data, and the interpretation of the modeling output are more important than the choice of the code itself. The ability of today’s codes and advanced computers to predict an outcome far exceeds the ability of hydrogeologists and geochemists to represent the physical and chemical properties of the site. The degree of confidence in the models is severely limited in part because the models are so complex that they cannot be easily reviewed by regulatory staff and the public. Water quality predictions should always be re-evaluated over time at mines sites and compared to site-specific water quality information as it becomes available. The efficacy of the mitigation measures should also be tested using predictive models and later confirmed with active monitoring. For this analysis, possible ranges in effectiveness of the mitigation measures (e.g., ranges in permeability values of liners) should be used in predictive models.

Predictive modeling of water quality at mine sites is an evolving science with inherent uncertainties. However, using the approaches described in this report, predictive water quality modeling and site characterization information can be reliably used to design protective mitigation measures and to estimate the costs of future remediation of hardrock mine sites.

1.0 INTRODUCTION

The art of predicting future water quality at hardrock mine sites has been practiced for at least the past 30 years. As part of the National Environmental Policy Act (NEPA), mines and other industrial facilities in the United States on federal land are required to estimate impacts to the environment, including direct impacts to water quality and indirect impacts that are later in time but still reasonably foreseeable (Kempton and Atkins, 2000; Bolen, 2002). Facilities on private land in the United States are often subject to State processes that may or may not require prediction of potential impacts to water resources. Other countries have followed a similar approach, largely based on the Environmental Impact Statement or Assessment of NEPA. A wide array of approaches has been used to predict water quality that could result from construction, proposed expansion, or other action at an industrial facility.

In this study, we review the methods and models used to predict water quality at hardrock mine sites, with an emphasis on the state of the art and on advantages and limitations of these techniques. Because water quantity and quality are interrelated, methods and models used to predict water quantity will also be discussed, but the emphasis will be on how these methods relate to water quality. This study brings together technical information on water-quality predictions at mine sites in a single report, and attempts to present a straight forward approach to using and evaluating the results of the methods and models used to predict water quality at mine sites. Approaches developed primarily in the United States, Canada, and Australia and applied in these countries and in other parts of the world, especially in the last 10 years, are discussed, and the format of the study is geared toward use by regulators of hardrock mines. The approach and results of this study could also be used by environmental managers at mine sites and community groups, and allows for the creation of a checklist for prediction methodology used at mine sites. Recommendations are made for improvements in water quality prediction methods and models.

2.0 THE NATURE OF PREDICTIONS

Although future predictions are often part of the business of science, most notably in the fields of meteorology and more recently climate change, scientists are generally uncomfortable with forward (future) predictions (Sarewitz, 1996). Forward predictions cannot be checked for accuracy until the future comes to pass. In the mining industry, the most common example of forward modeling is the prediction of pit lake water quality over time. Predictions of pit lake water quality and water-quality predictions in general have been acknowledged as having large uncertainties (Kempton, 2002), yet results from these predictions often form the basis of permit granting to the mining industry.

The principal use of modeling, according to Oreskes et al. (1994), should be to understand discrepancies between observed data and simulated results, test hypotheses, conduct sensitivity analyses, and explore “what-if” scenarios. If detailed site-specific information is available, an adequate conceptual model of the mine site, for example, can be developed to simulate current conditions or conditions in the recent past. If this is successful, an increased level of confidence can be placed in the use of this model to assess future site conditions (Mayer et al., 2003). However, because natural systems are never closed systems, because inputs to hydrologic and geochemical models are incompletely or only approximately known, and because of scaling problems in natural systems, models used to simulate natural processes cannot be verified (Oreskes et al., 1994).

The length of time over which a mine site will deviate from baseline or pre-mining conditions can be on the order of centuries to tens of thousands of years, as a result of potential delays in the generation or appearance of acid drainage (e.g., Morin et al., 1995; Kempton and Atkins, 2000) and the long “half-life” of releases from mining wastes. Therefore, the “future” at hardrock mine sites approximates the period of interest for nuclear waste disposal rather than that for more conventional industrial facilities. In addition, changes in the mine plan after permitting can add uncertainty to the predictions made early in the mining process. Inherent uncertainties, lag times, and the duration of contamination have led some practitioners of modeling at mine sites to emphasize ranges rather than precise values for water-quality predictions. At least three Environmental Impact Statements for mines in Nevada

(Battle Mountain Phoenix Project, 2001; Round Mountain, 1996; Twin Creeks, 1996) contain general statements about uncertainty, such as, “...there is considerable uncertainty associated with long-term predictions of potential impacts to groundwater quality from infiltration through waste rock...for these reasons, predictions should be viewed as indicators of long-term trends rather than absolute values.” While these statements are certainly true, modeling and predictions do have value as management tools and for helping to understand the biological and physicochemical systems at mine sites (Oreskes, 2000). In addition, water-quality predictions are used to make decisions about mitigation approaches at a mine site, and realistic predictions will ensure that the appropriate type of mitigation is chosen.

An optimistic approach to modeling would consider that our understanding of hydrochemical systems and the problem of relating models at different scales (from the atomic to the watershed level) will continue to advance by implementation of field and laboratory experiments that carefully extract one variable at a time to isolate and compare with the coupled numerical models available today, and by conducting post-audits of predictions. The level of complexity chosen for the model must reflect the scale at which the problem is addressed (White and Brantley, 1995), the availability of information, and the level of detail and accuracy/precision that is required (Banwart et al., 2002). In general, for problems of larger scale (e.g., predicting groundwater flow under a 20-km² area at a mine site) and with less available information, a less complex the model should be employed.