ENVIRONMENTAL MINE WASTE MANAGEMENT:

SUMMARY OF PREVENTION, CONTROL, AND TREATMENT STRATEGIES FOR PROBLEMATIC DRAINAGES

Appendices

Advances in Mine Waste Management Project
Progress Report to the Minerals Coordinating Committee

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APPENDIX 1

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A1.1. Passive Treatment Systems

2758. Skousen,Jeff (1997): Overview of passive systems for treating acid mine drainage. Green Lands 27, 34-43.

2884. Eger,Paul (1995): Notes from the National Inter-Agency Workshop on Wetlands. New Orleans, LA, April 3-7, 1995.

3217. Eger,Paul; Melchert,Glenn; Wagner,Jon (1998): Mine closure -- Can passive treatment be successful? In: 1998 Annual Meeting of the American Society for Surface Mining and Reclamation (ASSMR). (May 16-21, 1998, St. Louis, MO) (:) ASSMR,, .

3262. Hedin,Robert S; Nairn,Robert W; Kleinmann,Robert LP (1800): The passive treatment of coal mine drainage (Draft)., .

3639. McNee,JJ; Robertson,JD (2000): Development of a new water sampling device to measure biologically-available metals in natural waters and mine effluents. CIM Bulletin 93(1037), 54-57.

Van97 Kalin, M.; Smith, M.P. (1997) Microbial acid reduction in sediments- Concepts and application. V3.

a. Anoxic limestone drains

592. Brodie,GA; Britt,CR; Tomaszewski,TM; Taylor,HN (1991): Anoxic Limestone Drains to Enhance Performance of Aerobic Acid Drainage Treatment Wetlands - Experiences of the Tennessee Valley Authority. (Presented at Intl. Conf. on Constructed wetlands for Water Quality Improvement; October, 1991. Pensacola Fl) Unknown, Unknown. 10 plus schematics pages.

594. National Mine Land Reclamation Center (1992): Alkaline additions and anoxic drains passing the acid test. Minelands 4(1, Summer), 2.

595. Skousen,Jeffrey G; Faulkner,Ben (1992): Preliminary results of anoxic limestone drains in West Virginia. Minelands 4(1, Summer), 3-5.

598. Skousen,Jeff (1800): Anoxic limestone drains for acid mine drainage treatment. Green Lands Unknown, 30-35.

659. Oaks,Wendell R; Bowden,Joe (Eds.) (1991): Proceedings of the 1991 National Meeting of the American Society of Surface Mining and Reclamation. Vol. 1 and 2. Americal Society of Surface Mining and Reclamation, Princeton, West Virginia.

701. Hedin,Robert S; Nairn,Robert W (1992): Designing and sizing passive mine drainage treatment systems. In: Proceedings: Thirteenth Annual West Virginia Surface Mine Drainage Task Force Symposium, Ramada Inn, Morgantown, West Virginia, April 8-9, 1992. (Ed: West Virginia Surface Mine Drainage Task Force) West Virginia Surface Mine Drainage Task Force and West Virginia Mining and Reclamation Association, Morgantown, WV, .

702. Brodie,GA; Britt,CR; Tomaszewski,TM; Taylor,HN (1992): Anoxic limestone drains to enhance performance of aerobic acid drainage treatment wetlands -- The Tennessee Valey Authority. Presented at: 1992 West Virginia Surface Mine Drainage Task Force Symposium, Morgantown, West Virginia.

703. Watzlaf,George R; Hedin,Robert S (1993): A method for predicting the alkalinity generated by anoxic limestone drains. Poster Session Presented at: ASSMR Meeting in Spokane, May 1993.

1545. Nairn,Robert W; Hedin,Robert S; Watzlaf,George R (1992): Generation of alkalinity in an anoxic limestone drain. In: Achieving land use potential through reclamation. (ASSMR9-92) (Ed: American Society for Surface Mining and Reclamation) American Society for Surface Mining and Reclamation, WV, 206-219.

1682. Campbell,DB (1989): Some observations relative to the performance of flow-through rock drains. Chap. 9. In: Water Management at Minesites. (Proc. 13th Annual British Columbia Mine Reclamation Symposium) (Eds: Mining Association of British Columbia; Ministry of Energy,Mines and Petroleum Resources; Ministry of Environment) Ministry of Energy,Mines and Petroleum Resources, Victoria, BC, 119-128.

1747. Kleinmann,RLP; Hedin,RS (1993): Treat mine water using passive methods. Journal of Pollution Engineering 25(13), 20-22.

2453. Ziemkiewicz,Paul; Skousen,Jeff; Lovett,Ray (1994): Open limestone channels for treating acid mine drainage: A new look at an old idea. Green Lands 24, 36-41.

2618. Ziemkiewicz,Paul F; Brant,David L; Skousen,Jeffrey G (1996): Acid mine drainage treatment with open limestone channels. Green Lands 26(2), 33-40.

2743. Skousen,Jeff; Burnett,Mac; Bassage,Dave; Black,Courtney; Ziemkiewicz,Paul; Zucher,Dave (1997): The watershed approach to acid mine drainage abatement: Sovern Run. Green Lands 27, 43-49.
2814. Cambridge,M (1995): Use of passive systems for the treament and remediation of mine outflows and seepages. Minerals Industry International (May), 35-42.
2848. Ziemkiewicz,PF; Skousen,JG; Brant,DL; Sterner,PL; Lovett,RJ (1997): Acid mine drainage treatment with armored limestone in open limestone channels. J. Environ. Qual. 26, 1017-1024.
2911. Hedin,Robert S; Nairn,Robert W; Kleinmann,Robert LP (1994): Passive treatment of coal mine drainage. (Information Circular, 9389.) US Department of the Interior, Bureau of Mines, Pittsburgh, PA. 35 pages.
Pitt94 Hedin, R.S.; Watzlaf, G.R. (1994) The effects of anoxic limestone drains on mine water chemistry. V1.
Pitt94 Cooper, A.R. et al. (1994) Use of a bromide tracer to determine retention time of mine drainage in anoxic limestone drains. V2.
Pitt94 Hedin, R.S. et al. (1994) Performance of the Howe Bridge passive treatment system. V2.
Pitt94 Hedin, R.S. et al. (1994) Performance of the Morrison passive treatment system. V2.
Pitt94 Watzlaf, G.R. et al. (1994) The performance of the Jennings Environmental Center anoxic limestone drain. V2.
Pitt94 Yednock, B. (1994) Construction and performance of anoxic limestone drains installed to treat acid mine drainage on abandoned mine lands in West Virginia. V2.
Sud95 Brant, D.L. et al. (1995) Anoxic limestone foundation drains for AMD control in coal refuse piles.
Van97 Eger, P. et al. (1997) The use of a peat/limestone system to treat acid rock drainage. V3.
Van97 Wildeman, T.R. et al. (1997) Field assessment of Fe(III), Al, and dissolved (O_2) for passive treatment options. V4.
Sud99 Brant, D.L. et al. (1999) Passive removal of manganese from acid mine drainage at the Shade Mining Site, Somerset County, PA (USA). V3.

b. Constructed Wetlands

596. Brodie,Gregory A (1991): Staged, Aerobic Constructed Wetlands to Treat Acid Drainage - Case History of Fabius Impoundment 1 and Overview of the Tennessee Valley Authority's Program. (Presented at Intl. Conf. on Constructed wetlands for Water Quality Improvement; October, 1991. Pensacola Fl) Tennessee Valley Authority: Fossil and Hydro Power, Chattanooga, TN. 9 plus schematics pages.
597. Brodie,Gregory A (1991): Engineered wetlands for effective treatment of acid drainage - applications, results, and prospects in the Tennessee Valley. In: Proceedings of the 34th Annual Meeting of the Association of Engineering Geologists. (Ed: Association of Engineering Geologists) Association of Engineering Geologists, Chicago, IL, 558-568.
704. Brodie,Gregory A; Britt,Cynthia R; Taylor,Henry N (1992): Staged, aerobic constructed wetlands to treat acid drainage -- The Tennessee Valley Authority Program. Presented at: West Virginia Surface Mine Drainage Task Force Symposium, Morgantown, West Virginia.
785. Eger,Paul; Lapakko,Kim (1989): Use of wetlands to remove nickel and copper from mine drainage. In: Constructed Wetlands for Wastewater Treatment. (Ed: Hammer,DA) Lewis Publishers, Chelsea, MN, 780-787.
790. Darnall,DW; Greene,B; Hosea,M; McPherson,RA; Henzl,M; Alexander,MD (1986): Recovery of heavy metals by immobilized algae. In: Trace metal removal from aqueous solution. (Ed: Unknown) University of Warwick, Unknown, 1-24.
840. Hammer,David E; Kadlec,Robert H (1983): Design principles for wetland treatment systems. United States Environmental Protection Agency, Office of Research and Development, Ada, OK. 244 pages.
841. Kleinmann,Bob; Brooks,Rob; Huntsman,Brent; Pesavento,Ben (1800): Constructing wetlands for the treatment of mine water. Course notes. (N)
842. Ilhardt,Bonnie (1985): Drummond bog wastewater treatment system: Summary of water quality monitoring data collected during 1983-1984. Paper.
846. Babcock,MF; Evans,DW; Alberts,JJ (1983): Comparative uptake and translocation of trace elements from coal ash by *typha latifolia*. Science 28, 203-214.

849. Gersberg,Richard M; Lyon,Stephen R; Elkins,Bert V; Goldman,Charles R (1984): The removal of heavy metals by artificial wetlands. RS Kerr Envronmental Research Laboratory and US Environmental Protection Agency, Ada, OK.
861. Pahlman,John E; Khalafalla,Sanaa E (1800): Use of lignochemicals and humic acids to remove heavy metals from process waste streams. (Report of Investigations 9200) U.S. Department of the Interior, Bureau of Mines, Pittsburgh, PA. 9 pages.
863. Girts,Michelle A; Kleinmann,Robert LP (1986): Constructed wetlands for treatment of acid mine drainage: A preliminary review. In: 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation. (Ed: Unknown) Unknown, Unknown, 165-171.
864. Girts,MN; Kleinmann,RLP; Erickson,PM (1987): Performance data on typh and sphagnum wetlands constructed to treat coal mine drainage. Paper presented at the 8th Annual Surface Mine Drainage Task Force Symp, Morgantown, WV, April 7-8.
865. Kleinmann,Robert LP (1800): A biological alternative to conventional AMD treatment. Unknown.
866. Chironis,Nocholas P (1987): Mine-built ponds economically clear acid mine waters. Coal Age (January), 58-61.
868. Girts,MA; Kleinmann,RLP (1986): Constructing wetlands for treatment of mine water. Paper presented at Society of Mining Engineers Fall Meeting, Sept 7-10, St. Louis, MO.
871. Unknown (1986): Proposal to the Office of Surface Mining for constructing wetlands for treatment of acid mine drainage. U.S. Bureau of Mines and Brehm Laboratory, Pittsburgh, PA and Dayton, OH.
873. Unknown (1989): Bureau, EPA studies continue on wetlands to control coal mine drainages. Mining Engineering (August), 816.
881. Holm,J David; Jones,Scott (1985): Passive mine drainage treatment: An effective low-cost alternative. In: 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation. (Ed: Unknown) Unknown, Unknown, 115-120.
882. Wildeman,Thomas; Olsen,Roger; Sandza,Walter (1800): Big five tunnel mine drainage treatment demonstration site. Idaho Springs, CO; EPA Superfund Site.
884. Wolverton,BC (1987): Aquatic plants for wastewater treatment: an overview. Chap. 1. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 3,11-13.
885. Wentz,WA (1987): Ecological/environmnetal perspectives on the use of wetlands in water treatment. Chap. 1. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 17.
886. Tchobanoglous,G (1987): Aquatic plant systems for water treatment. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 27.
887. Lakshman,G (1987): Ecotechnological opportunities for aquatic plants- A survey of utilization options. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 49.
889. Kleinmann,RLP; Girts,MA (1987): Acid mine water treatment in wetlands: An overview of an emergent technology. Chap. 2. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 255-261.
890. Heaton,C; Frame,J; Hardy,JK (1987): Lead uptake by the water hyacinth. Chap. 3. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 463-470.
891. Wills,RA; Pierson,SS (1987): Absorption of Fe^{59} by water hyacinths. Chap. 3. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 471-478.
892. Jamil,K; Rao,PVR; Jamil,MZ (1987): Studies on efficacy of *eichhornia crassipes* (mart) solms in removing heavy metals from aquatic medium and their effects on the plant tissues. Chap. 3. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 479-485.
895. O'Keeffe,DH; Wiese,TE; Benjamin,MR (1987): Effects of positional isomerism on the uptake of

monosubstituted phenols by the water hyacinth. Chap. 3. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 505-512.

896. DeBusk,TA; Reddy,KR (1987): Wastewater treatment using floating aquatic macrophytes: Contaminant removal processes and management strategies. Chap. 4. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 643-656.

897. Brodie,GA; Hammer,DA; Tomljanovich,DA (1987): Treatment of acid drainage from coal facilities with man-made wetlands. Chap. 5. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 903-912.

898. Knight,RL (1987): Effluent distribution and basin design for enhanced pollutant assimilation by freshwater wetlands. Chap. 5. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 913-921.

899. Middlebrooks,E Joe (1987): Research and development needs for utilization of aquatic plants for water treatment and resource recovery: Engineering status. Chap. 6. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 1009-1011.

900. Corey,John C (1987): Research and development needs for utilization of aquatic plants for water treatment and resource recovery: Plant-water-sediment processes. Chap. 6. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 1011-1013.

901. Hall,Carl W (1987): Research and development needs for utilization of aquatic plants for water treatment and resource recovery: Resource recovery. Chap. 6. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 1013-1016.

902. Odum,William E (1987): Research and development needs for utilization of aquatic plants for water treatment and resource recovery: Ecological considerations. Chap. 6. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 1016-1018.

903. Davidson,James M (1987): Research and development needs for utilization of aquatic plants for water treatment and resource recovery: Environmental issues. Chap. 6. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 1018-1020.

904. Reed,Sherwood C (1987): Research and development needs for utilization of aquatic plants for water treatment and resource recovery: Summary. Chap. 6. In: Aquatic Plants for Water Treatment and Resource Recovery. (Eds: Reddy,KR; Smith,WH) Magnolia Publishing,Inc., Orlando, FL, 1020-1022.

905. Brooks,RP; Unz,RF; Davis,LK; Tarutis,WJ Jr; Yanchunas,J Jr (1990): Long-term removal and retention of iron and manganese from acidic mine drainage by wetlands-Volume I: Methods, results, and appendices. Vol. 1. U.S. Department of the Interior, Bureau of Mines, Washington,DC.

906. Dollhopf,DJ; Goering,JD; Rennick,RB; Morton,RB; Gauger,WK; Guckert,JB; Jones,PM; Cooksey,KC; Bucklin,KE; Weed,Rebecca; Lehman,MM (1988): Hydrochemical, vegetational and microbiological effects of a natural and a constructed wetland on the control of acid mine drainage. Reclamation Research Unit, Montana State University, Bozeman, MT. 214 pages.

907. Hammack,RW; Hedin,RS (1989): Microbial sulfate reduction for the treatment of acid mine drainage: A laboratory study. Presented at 9th Annual West Virginia Surface Mine Drainage Task Force Symposium, Morgan Town, WV, April 25-26.

1097. Anonymous (1991): Constructed wetlands, passive treatment of mine drainage. The Mining Record Unknown(4 December), 52.

1327. Wieder,R Kelman (1991): Spatial and temporal patterns in surface and subsurface water chemistry in wetlands constructed for acid coal mine drainage (AMD) treatment. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 3. (Ed: MEND Program) Quebec Mining Association, Ottawa, 507-527.

1328. Taddeo,Frank J; Wieder,R Kelman (1991): The accumulation of iron sulfides in wetlands constructed

for acid coal mine drainage (AMD) treatment. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 3. (Ed: MEND Program) Quebec Mining Association, Ottawa, 529-547.

1329. Hendricks,AC (1991): The use of an artificial wetland to treat acid mine drainage. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 3. (Ed: MEND Program) Quebec Mining Association, Ottawa, 549-558.

1330. Calabrese,Joseph P; Sexstone,Alan J; Bhumbla,Devinder K; Bissonnette,Gary K; Sencindiver,John C (1991): Application of constructed cattail wetlands for the removal of iron from acid mine drainage. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 3. (Ed: MEND Program) Quebec Mining Association, Ottawa, 559-575.

1349. Klusman,Ronald W (1991): Computer modeling of biogeochemical processes operating in a constructed wetland. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. (Ed: MEND Program) Quebec Mining Association, Ottawa, 235-255.

1359. Cairns,JE; McCready,R; Kalin,M (1991): Integrated field and laboratory experiments in ecological engineering methods for acid mine drainage treatment. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. (Ed: MEND Program) Quebec Mining Association, Ottawa, 409-425.

1361. Wheeler,WN; Kalin,M; Cairns,JE (1991): The ecological response of a bog to acidic coal mine drainage - deterioration and subsequent initiation of recovery. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. (Ed: MEND Program) Quebec Mining Association, Ottawa, 449-464.

1362. Stark,Lloyd R; Wenerick,William R; Wuest,Paul J; Williams,Frederick M; Stevens,S Edward Jr (1991): Adding a carbon supplement to simulated treatment wetlands improves mine water quality. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. (Ed: MEND Program) Quebec Mining Association, Ottawa, 465-483.

1363. Karathanasis,AD; Thompson,YL (1991): Metal speciation and retention patterns in a high metal load acid mine constructed wetland of southeastern Kentucky. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. (Ed: MEND Program) Quebec Mining Association, Ottawa, 485-498.

1365. Brown,Ann (1991): Proposal for the mitigation of acid leaching from tailings using a cover of muskeg peat. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. (Ed: MEND Program) Quebec Mining Association, Ottawa, 517-527.

1455. Brodie,Gregory A; Hammer,Donald A; Tomljanovich,David A (1988): Constructed wetlands for acid drainage control in the Tennessee Valley. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 325-331.

1456. Stark,Lloyd R; Kolbash,Ronald L; Webster,Harold J; Stevens,S Edward Jr; Dionis,Kim A; Murphy,Earl R (1988): The SIMCO #4 Wetland: Biological patterns and performance of a wetland receiving mine drainage. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 332-344.

1458. Hiel,Michael T; Kerins,Francis J Jr (1988): The Tracy Wetlands: A case study of two passive mine drainage treatment systems in Montana. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 352-358.

1459. Secindiver,JC; Bhumbla,DK (1988): Effects of cattails (*Typha*) on metal removal from mine drainage. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 359-366.

1460. Samuel,David E; Secindiver,John C; Rauch,Henry W (1988): Water and soil parameters affecting growth of cattails: Pilot studies in West Virginia mines. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 367-374.

1461. Wieder,R Kelman (1988): Determining the capacity for metal retention in man-made wetlands constructed for treatment of coal mine drainage. In: Mine drainage and surface mine reclamation. Vol.

1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 375-381.

1462. Hedin,Robert S; Hyman,David M; Hammack,Richard W (1988): Implications of sulfate-reduction and pyrite formation processes for water quality in a constructed wetland: Preliminary observations. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 382-388.

1463. Brodie,Gregory A; Hammer,Donald A; Tomljanovich,David A (1988): An evaluation of substrate types in constructed wetlands acid drainage treatment systems. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 389-398.

1464. Vail,WJ; Wilson,S; Riley,RK (1988): Isolation and culture of a manganese-oxidizing bacterium from a man-made cattail wetland. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 399.

1465. Webster,HJ; Stark,LR; Stevens,SE Jr (1988): Screening of mosses and algae in greenhouse experiments for their ability to remove iron from water. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 399.

1466. Kalin,M (1988): Ecological engineering and biological polishing: Its application in close-out of acid generating waste management areas. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 399.

1467. Mitsch,WJ (1988): Wetlands and mine drainage - An ecotechnology approach. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 400.

1468. Brown,A; Mathur,SP; Kushner,DJ (1988): Peat blanket to lock acid mine spoils in a self-sustaining ecosystem. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 400.

1469. Behling,RE (1988): Wetland/riparian reconstruction following surface mining: Part III. Recommendations on channel morphology to support a wet meadow. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 400.

1470. Demko,TM (1988): A staged wetland treatment system for mine water with low pH and high metal concentrations. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 401.

1471. Wildeman,TR; Laudon,LS; Howard,EA (1988): Construction of a wetland demonstration site for a metal-mine drainage. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 401.

1508. Hammer,Donald A (1990): Constructed wetlands for acid water treatment: An overview of emerging technology. In: Acid mine drainage: Designing for closure. (Presented at GAC/MAC Joint Annual Meeting in Vancouver, May 16-18) (Eds: Gadsby,John W; Malick,James A; Day,Stephen J) BiTech Publishers Ltd., Vancouver, BC, 381-394. (N)

1509. Gormely,Lynton S; Tessier,Ron; Kistritz,Ron U; Sobolewski,Andre (1990): Planned constructed wetland experiment for treating AMD at Bell Copper. In: Acid mine drainage: Designing for closure. (Presented at GAC/MAC Joint Annual Meeting in Vancouver, May 16-18) (Eds: Gadsby,John W; Malick,James A; Day,Stephen J) BiTech Publishers Ltd., Vancouver, BC, 395-405. (N)

1510. Kalin,Margarete M (1990): Ecological engineering applied to base metal mining wastes. In: Acid mine drainage: Designing for closure. (Presented at GAC/MAC Joint Annual Meeting in Vancouver, May 16-18) (Eds: Gadsby,John W; Malick,James A; Day,Stephen J) BiTech Publishers Ltd., Vancouver, BC, 407-414. (N)

1528. Silver,M (1987): Aquatic plants and bog covers to prevent acid generation - Base metal tailings. In: Proc. acid mine drainage seminar/workshop. (Seminar held in Halifax, Nova Scotia, March 23-26) (Ed: Environment Canada) Environment Canada, Ottawa, 411-438.

1531. Pesavento,Benjamin G (1987): Factors to be considered in the use of wetlands to treat acid mine

drainage. In: Proc. acid mine drainage seminar/workshop. (Seminar held in Halifax, Nova Scotia, March 23-26) (Ed: Environment Canada) Environment Canada, Ottawa, 499-505.

1537. American Society for Surface Mining and Reclamation (1992): Achieving land use potential through reclamation. (Proc. 9th Annual National Meeting of the American Society for Surface Mining and Reclamation, Duluth, MN, June 14-18; ASSMR9-92) American Society for Surface Mining and Reclamation, WV. 763 pages.

1539. Bolis,Judith L; Wildeman,Thomas R; Dawson,Helen E (1992): Hydraulic conductivity of substrates used for passive acid mine drainage treatment. In: Achieving land use potential through reclamation. (ASSMR9-92) (Ed: American Society for Surface Mining and Reclamation) American Society for Surface Mining and Reclamation, WV, 79-89.

1540. Rabenhorst,Martin C; James,Bruce R; Shaw,Joey N (1992): Evaluation of potential wetland substrates for optimizing sulfate reduction. In: Achieving land use potential through reclamation. (ASSMR9-92) (Ed: American Society for Surface Mining and Reclamation) American Society for Surface Mining and Reclamation, WV, 90-97.

1541. Eger,P; Melchert,G (1992): The design of a wetland treatment system to remove trace metals from mine drainage. In: Achieving land use potential through reclamation. (ASSMR9-92) (Ed: American Society for Surface Mining and Reclamation) American Society for Surface Mining and Reclamation, WV, 98-107.

1549. Duggan,Laura A; Wildeman,Thomas R; Updegraff,David M (1992): The aerobic removal of manganese from mine drainage by an algal mixture containing *cladophora*. In: Achieving land use potential through reclamation. (ASSMR9-92) (Ed: American Society for Surface Mining and Reclamation) American Society for Surface Mining and Reclamation, WV, 241-248.

1550. Duddleston,KN; Fritz,E; Hendricks,AC; Roddenberry,K (1992): Anoxic cattail wetland for treatment of water associated with coal mining activities. In: Achieving land use potential through reclamation. (ASSMR9-92) (Ed: American Society for Surface Mining and Reclamation) American Society for Surface Mining and Reclamation, WV, 249-254.

1551. Frostman,Theodore M (1992): Constructed peat/wetland treatment systems for heavy metal removal. In: Achieving land use potential through reclamation. (ASSMR9-92) (Ed: American Society for Surface Mining and Reclamation) American Society for Surface Mining and Reclamation, WV, 255-259.

1552. Haffner,WM (1992): Palmerton zinc superfund site constructed wetlands. In: Achieving land use potential through reclamation. (ASSMR9-92) (Ed: American Society for Surface Mining and Reclamation) American Society for Surface Mining and Reclamation, WV, 260-267.

1559. Staub,Margaret W; Cohen,RH (1992): A passive mine drainage treatment system as a bioreactor: Treatment efficiency, pH increase, and sulfate reduction in two parallel reactors. In: Achieving land use potential through reclamation. (ASSMR9-92) (Ed: American Society for Surface Mining and Reclamation) American Society for Surface Mining and Reclamation, WV, 550-562.

1560. Eger,P (1992): The use of sulfate reduction to remove metals from acid mine drainage. In: Achieving land use potential through reclamation. (ASSMR9-92) (Ed: American Society for Surface Mining and Reclamation) American Society for Surface Mining and Reclamation, WV, 563-575.

1589. Michelutti,RE (1988): Minimizing metal contaminated seepages from high sulphide tailings by establishing a marsh cover. Chap. 27. In: Proc. International Conference on Control of Environmental Problems from Metal Mines. (Eds: State Pollution Control Authority; Federation of Norwegian Industries) State Pollution Control Authority, Norway, 17pages.

1677. Whitehead,Alan J; Kelso,Bryan W; Malick,James G (1989): Nitrogen removal from coal mine wastewater using a pilot scale wetland - Year 1 results. Chap. 4. In: Water Management at Minesites. (Proc. 13th Annual British Columbia Mine Reclamation Symposium) (Eds: Mining Association of British Columbia; Ministry of Energy,Mines and Petroleum Resources; Ministry of Environment) Ministry of Energy,Mines and Petroleum Resources, Victoria, BC, 37-50.

1802. Tarleton,Amy L; Lang,Gerald E; Wieder,R Kelman (1984): Removal of iron from acid mine drainage by sphagnum peat: Results from experimental laboratory microcosms. In: 1984 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation. (Ed: Unknown) Unknown, Unknown, 413-420.

1803. Wieder,R Kelman; Lang,Gerald E; Whitehouse,Alfred E (1985): Metal removal in sphagnum-dominated wetlands: experience with a man-made wetland system. In: Wetlands and water management on mined lands. (Eds: Brooks,Robert P; Samuel,David E; Hill,Janice B) Pennsylvania State University, PA, 353-364.

1811. Dubuc,Y; Janneteau,P; Labonte,R; Roy,C; Briere,F (1986): Domestic wastewater treatment by peatlands in a northern climate: A water quality study. Water Resources Bulletin 22(2), 297-303.

1812. Gersberg,RM; Elkins,BV; Goldman,CR (1984): Use of artificial wetlands to remove nitrogen from wastewater. J. Water Pollut. Control Fed. 56(2), 152-156.

1813. Kepler,DA; Brenner,FJ (1986): Acid mine drainage abatement in man-made wetland systems. Presented at Conference on Research and Applications of: Aquatic Plants for Water Treatment and Resource Recovery, Orlando, FL, July 20-24.

1814. Brodie,GA; Hammer,DA; Tomljanovich,DA (1986): Treatment of acidic drainage from coal facilities with man-made wetlands. Presented at Conference on Research and Applications of: Aquatic Plants for Water Treatment and Resource Recovery, Orlando, FL, July 20-24.

1817. Rogers,KH; Herrera,G (1986): Sulphate reduction in a wetland receiving mining effluents: Preliminary implications for treatment in artificial wetlands. Presented at Conference on Research and Applications of: Aquatic Plants for Water Treatment and Resource Recovery, Orlando, FL, July 20-24.

1829. Knight,RL (1986): Design features for enhanced pollutant assimilation by freshwater wetlands. Presented at Conference on Research and Applications of: Aquatic Plants for Water Treatment and Resource Recovery, Orlando, FL, July 20-24.

1833. LaBaugh,James W (1986): Wetland ecosystem studies from a hydrologic perspective. Water Resources Bulletin 22(1), 1-10.

1834. Emerick,JC; Howard,EA (1988): Using wetlands for the control of western acid mine drainage. Presented at SME Annual Meeting, Phoenix, AZ, January 25-28.

1835. Kleinmann,Robert LP; Tiernan,Thomas O; Solch,Joseph G; Harris,Richard L (1983): A low-cost, low-maintenance treatment system for acid mine drainage using sphagnum moss and limestone. In: 1983 Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation. (Ed: Unknown) Unknown, Unknown, 241.

1838. Girts,Michelle A; Kleinmann,Robert LP (1986): Contructed wetlands for treatment of acid mine drainage: A preliminary review. In: 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation. (University of Kentucky, Lexington, KY, Dec 8-11) (Ed: Unknown) Unknown, Unknown, 165.

1839. Cole,Charles Andrew (1986): Morphometry, hydrology, and some associated water quality fluctuations in a surface mine wetland complex in Southern Illinois. In: 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation. (University of Kentucky, Lexington, KY, Dec 8-11) (Ed: Unknown) Unknown, Unknown, 157.

1987. Apps,JA (1974): Capacity of Wisconsin peat to adsorb toxic metals and organic mill reagents which may occur in seepages from the propsed Flambeau waste containment area. Memo of outline and tables only.

2006. Williams,TC (1979): The history and development of the Houghton Lake wetland-wastewater treatment project. Presented at Conference on Fresh-Water Wetlands and Sanitary Wastewater Disposal, MacMullan Conference Center, Higgins Lake, Michigan.

2007. Bastian,Robert K (1979): EPA interest in the potential for wetland treatment of wastewater. Presented at Conference on Fresh-Water Wetlands and Sanitary Wastewater Disposal, MacMullan Conference Center, Higgins Lake, Michigan.

2008. Kadlec,Robert H (1979): Performance of the Houghton Lake, Michigan wetland treatment system. Presented at Conference on Fresh-Water Wetlands and Sanitary Wastewater Disposal, MacMullan Conference Center, Higgins Lake, Michigan.

2009. Bennett,Carl L (1979): The concerns of a public servant when secondarily treated effluent is spread across a wetland. Presented at Conference on Fresh-Water Wetlands and Sanitary Wastewater Disposal, MacMullan Conference Center, Higgins Lake, Michigan.

2010. Bevis,Frederick B; Kadlec,Robert H (1979): Effect of long-term dishcarge of wastewater on a

Northern Michigan wetland. Presented at Conference on Fresh-Water Wetlands and Sanitary Wastewater Disposal, MacMullan Conference Center, Higgins Lake, Michigan.

2011. Sutherland,Jeffrey C (1979): The Vermontville, Michigan, watewater-grown volunteer seepage wetlands: Water quality and engineering implications. Presented at Conference on Fresh-Water Wetlands and Sanitary Wastewater Disposal, MacMullan Conference Center, Higgins Lake, Michigan.

2012. Bevis,Frederick B (1979): Ecological considerations in the management of wastewater-engendered volunteer wetlands. Presented at Conference on Fresh-Water Wetlands and Sanitary Wastewater Disposal, MacMullan Conference Center, Higgins Lake, Michigan.

2075. Beers,WF; Ciolkosz,EJ; Kardos,LT (1974): Soil as a medium for the renovation of acid mine drainage water. In: Symposium on 5th Coal Mine Drainage Research. (Ed: Unknown) Unknown, Louisville, KY, 160-171.

2088. Ontario Ministry of the Environment,Technical Support Section (1982): A chemical and biological assessment of waters impacted by active gold mining operations in the Red Lake area. Ministry of the Environment, Ontario.

2109. Eger,Paul; Lapakko,Kim; Weir,Anne (1980): Heavy metals study: 1979 Progress report on the field leaching and reclamation program and the removal of metals from stockpile runoff by peat and tailings. Minnesota Department of Natural Resources-Division of Minerals, St. Paul, MN.

2261. Millenacker,Daniel J (1985): Passive technique for removing trace metals from mine drainage. (Presented at 1984 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation, Lexington, KY, Dec. 2-7) U.S. Bureau of Mines, Minneapolis, MN.

2263. Merian,Ernest (1984): Metals & aquatic contamination workshop. Environ. Sci. Technol. 28(3), 144A-146A.

2281. Wieder,R Kelman; Shupack,Saul I (1800): The use of wetlands to treat acid mine drainage: Growth responses of sphagnum and mechanisms of metal retention in peat. 12-month Progress Report; EPA Assistance ID No. R-812379-01-0; 18 pages.

2282. Wieder,R Kelman; Shupack,Saul I (1800): The use of wetlands to treat acid mine drainage: Growth responses of sphagnum and mechanisms of metal retention in peat. 18-month Progress Report; EPA Assistance ID No. R-812379-01-0; 13 pages.

2285. Nawrot,JR; Yaich,SC (1982): Habitat enhancement of coal mine slurry impoundments though wetland development. In: Proc. 9th Annual Conference of Wetland Restoration and Creation. (Conference held at Tampa, FL, May 20-21) (Ed: Unknown) Cooperative Wildlife Research Laboratory, Sourthern Illinois University, Carbondale, IL, Unknown. (N)

2286. Nawrot,JR; Yaich,SC (1982): Slurry discharge management for wetland soils development. In: Symposium on Surface Mining Hydrology, Sedimentology and Reclamation. (Conference held at University of Kentucky, Lexington, KY, Dec. 5-10) (Ed: Unknown) Cooperative Wildlife Research Laboratory, Sourthern Illinois University, Carbondale, IL, 11-18. (N)

2288. Nawrot,JR (1985): Wetland development on coal mine slurry impoundments: Principles, planning, and practices. In: Wetlands and Water Management on Mined Lands Conference. (Conference held on October 23-24) (Ed: Unknown) Cooperative Wildlife Research Laboratory, Sourthern Illinois University, Carbondale, IL, 161-172. (N)

2289. Warburton,DB; Klimstra,WB; Nawrot,JR (1985): Aquatic macrophyte and planting practices for wetland establishment. In: Procceedings, Wetlands and Water Management on Mined Lands. (Conference held at Pennsylvania State University, University Park, PA) (Eds: Brooks,RP; Samuel,DE; Hill,JB) Cooperative Wildlife Research Laboratory, Sourthern Illinois University, Carbondale, IL, 138-152. (N)

2302. Anonymous (1994): Wetlands research. Land and Water (March/April), 53.

2325. Larratt Aquatic Consulting Ltd (1993): Bibliography for utillizing aquatic communities for treatment of Brenda Mines wastewater. List of references.

2329. Dunabin,Janet S; Bowmer,Kathleen H (1992): Potential use of constructed wetlands for treatment of industrial wastewaters containing metals. The Science of the Total Environment 111, 151-168.

2332. Rogers,KH; Breen,PF; Chick,AJ (1991): Nitrogen removal in experimental wetland treatment systems: evidence for the role of aquatic plants. Research Journal Water Pollution Control Federation 63(7,

November/December), 934-941.
2333. Rogers,KH; Breen,PF; Chick,AJ (1990): Hydraulics, root distribution and phosphorus removal in experimental wetland systems. In: Constructed wetlands in water pollution control: Proceedings of the International Conference on the Use of Constructed Wetlands in Water Pollution Control, Cambridge, UK, September 24-28, 1990. (Eds: Cooper,PF; Finlander,BC) Permagon Press, Oxford, 587-590.
2505. Gusek,James J (1995): Passive-treatment of acid rock drainage: What is the potential bottom line? Mining Engineering 47(March), 250-253.
2514. Bender,J; Gould,JP; Vatcharapijarn,Y; Young,JS; Phillips,P (1994): Removal of zinc and manganese from contaminated water with cyanobacteria mats. Water Environment Research 66(5, July/August), 679-683.
2680. Sencindiver,John C; Skousen,Jeffrey G (1991): Wetlands for acid mine drainage treatment. In: Enery in the Nineties. (:) ASCE,, 294-299.
2683. Kleinmann,Robert LP (1990): Acid mine water treatment using engineered wetlands. In: Acid mine water in pyritic enviornments (Lisboa International Symposium, September 16-19, 1990). Vol. 9. (:),, 269-276.
2734. Chambers,PA; Prepas,EE (1990): Competition and coexistence in submerged aquatic plant communities: the effects of species interactions versus abiotic factors. Freshwater Biology 23, 541-550.
2735. Nawrot,JR; Warburton,DB; Wiram,VP (1997): Wetland reclamation of the AMAX Ayrshire slurry impoundment. Coal (May), .
2881. Fullerton,William T; Long,Stephen G (1800): Wetland creation in a river valley disturbed by dredge boat mining. AWRA publication and/or conference proceeding.
2923. Lapakko,Kim; Eger,Paul (1983): Passive Treatment of Sulfide Stockpile Runoff. In: Environmental Engineering. (Eds: Medine,Allen; Anderson,Michael) (1983 National Conference Proceedings of the ASCE Specialty Conference, Boulder, Colorado, July 6-8, 1983.) American Society of Civil Engineers, New York, New York, 643-651.
3067. Eger,Paul; Wagner,Jon; Melchert,Glenn (1996): The use of overland flow wetland treatment systems to remove nickel from neutral mine drainage. In: . (Presented at 1996 Annual Meeting of the American Society fpr Surface Mining and Reclamation (ASSMR), Knoxville, TN, May 18-23, 1996) (:),, .
3116. Anonymous (1991): Constructed wetlands reduce cost of treating coal mine drainage. Technololgy Transfer Update (US Bureau of Mines), 1-2.
3134. Cole,Stephen (1998): The emergence of treatment wetlands. Environ. Sci. Technol. 32, 218A-223A.
3193. Ward,Jeanette L; Tsukamoto,Timothy; Miller,Glenn (1997): Remediation of acid mine drainage at an abandoned mine site by a natural wetland and a constructed wetland. In: Amercian Chemical Society 214th National Meeting. Vol. Division of Geochemistry. (September 7-11, 1997 Las Vegas, NV) (:) American Chemical Society, Washington DC, .
3386. Black,Courtney; Ziemkiewicz,Paul; Skousen,Jeff (1999): Adding alkalinity to water by limestone leach beds. Green Lands 29, 49-53.
3494. Kleinmann,Robert LP; Tiernan,Thomas O; Harris,Richard L (1983): A low-cost, low-maintenance treatment system for acid mine drainage using sphagnum moss and limestone. In: Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation. (Eds: Graves,Donald H; DeVore,R William) University of Kentucky, Lexington, Kentucky, 241-245.
3571. Anonymous (1988): Constructed wetlands tour, April 21, 1988. Tour description.
Pitt94 Bechard, G. et al. (1994) Microcosm model to study microbial groups involved in AMD treatment. V2.
Pitt94 Borek, S.L. et al. (1994) Evaluation of organic additives used to enhance bacterial sulfate reduction in mine water treatment systems.
Pitt94 Brenner, E.K. et al. (1994) Bacterial metabolism in acid mine drainage. V2.
Pitt94 Brickett, L.A.; Edenborn, H.M. (1994) The role of bacteria in the retention of Fe and Mn in a constructed wetland receiving coal mine drainage.
Pitt94 Calabrese, J.P. et al. (1994) Long-term study of constructed model wetlands for treatment of acid mine drainage. V2.

Pitt94 Davis, L.K. (1994) Constructed wetlands handbook. V2.
Pitt94 DeLeo, M. et al. (1994) Constructed vertical flow aerated wetlands designed for the removal of manganese from acidic mine drainage. V2.
Pitt94 Dietz, J.M. et al. (1994) Evaluation of acidic mine drainage treatment in constructed wetland systems. V1.
Pitt94 Eddy, D.P. (1994) Treatment of acid mine water with a sequential cell constructed wetland. V2.
Pitt94 Edwards, G.S.; Mays, P.A. (1994) Bioaccumulation of metals in constructed wetlands used to treat acid mine drainage. V2.
Pitt94 Eger, P. et al. (1994) Metal removal in wetland treatment systems. V1.
Pitt94 Eger, P. (1994) The use of sulfate reduction to remove metal from acid mine drainage. V2.
Pitt94 Faulkner, B.B.; Skousen, J.G. (1994) Treatment of acid mine drainage by passive treatment systems. V2
Pitt94 Fyson, A. et al. (1994) Arsenic and nickel removal by wetland sediments. V1.
Pitt94 Garbutt, K. et al. (1994) The tolerance of wetland plant species to acid mine drainage: A method of selecting plants species for use in constructed wetlands receiving mine drainage.
Pitt94 Hellier, W.W. et al. (1994) Best professional judgement analysis for constructed wetlands as a best available technology for the treatment of post-mining groundwater seeps. V1.
Pitt94 Hellier, W.W. (1994) The Bark Camp Run demonstration constructed wetlands. V2
Pitt94 Kalin, M. et al. (1994) The application of ecological engineering to acid coal seepages in eastern Canada. V2.
Pitt94 Kepler, D.A.; McCleary, E.C. (1994) Successive alkalinity-producing systems (SAPS) for the treatment of acidic mine drainage. V1.
Pitt94 Kuyucak, N.; St-Germain, P. (1994) In situ treatment of acid mine drainage by sulfate reducing bacteria in open pits: scale-up experiments. V2.
Pitt94 Kuyucak, N.; St-Germain, P. (1994) Possible options for in situ treatment of acid mine drainage seepages.V2.
Pitt94 Magness, M. C.; Rabenhorst, M.C. (1994) Remediation of mine drainage in constructed wetlands: Effects of pH and iron concentration. V2.
Pitt94 Phillips, P. et al. (1994) Manganese and iron removal from coal mine drainage by use of green algae-microbial mat consortium. V1.
Pitt94 Rowley, M.V. et al. (1994) The biosulfide process: Integrated biological/chemical acid mine drainage treatment- results of laboratory piloting. V1.
Pitt94 Shelp, G. et al. (1994) An evaluation of a peat-wood chip-microflora admixture to act as an ameliorant for acid mine drainage. V2.
Pitt94 Stark, L.R. et al. (1994) Iron retention and vegetative cover at the Simco constructed wetland: an appraisal through year eight of operation.
Pitt94 Tarutis, W.J. Jr. ; Unz, R.F. (1994) Iron and manganese dynamics in laboratory wetland mesocosms: Implications for coal mine drainage treatment. V2.
Pitt 94 Wildeman, T. et al. (1994) Laboratory and pilot-scale studies on the treatment of acid rock drainage at aclosed gold-mining operation in California. V2.
Pitt94 Wildeman, T.R. et al. (1994) Proof-of-principle studies for passive treatment of acid rock drainage and mill tailing solutions from a gold operation in Nevada. V2.
Pitt94 Williams, F.M. et al. (1994) Water quality and flow rates during storm events at two constructed wetlands receiving mine drainage. V2.
Pitt94 Wise, K.M.; Mitsch, W.J. (1994) Pre- and post- construction analysis of a wetland used for mine drainage control. V2.
Sud95 Blowes, D.W. et al. (1995) Treatment of mine drainage water using in situ permeable reactive walls.
Sud95 Borek, S.L. et al. (1995) Ability of cheese whey to support bacterial sulfate reduction in mine water treatment systems.
Sud95 Eger, P.; Wagner, J. (1995) Sulfate reduction for the treatment of acid mine drainage; Long term solution or short term fix?
Sud95 Jones, D.R. et al. (1995) Passive treatment of mine water.

Sud95 Sobolewski, A. et al. (1995) Copper removal from mine drainage by an experimental wetland at Bell Copper Mine, Smithers, BC.
Sud95 Waybrant, K.R. et al. (1995) Selection of reactive mixtures for the prevention of acid mine drainage using porous reactive walls.
Tmw98 Willow, M. et al. (1998) Factors affecting the efficiency of passive mine drainage treatment systems.
Tmw99 Anderson, R.C.; Hansen, B.G. (1999) Mine waste and water management at the Upper Blackfoot Mining Complex. pg 715.
Tmw99 McCarthy, D. et al. (1999) Evaluation of wetland treatment for the removal of metals from mining impacted groundwater. pg 725.
Sud99 Kalin, M. et al. (1999) Maintenance-free microbial treatment of AMD: four years of performance. V3.
Sud99 Sanders, F. et al. (1999) The Mike Horse mine, MT, integrated wetland treatment system: an update. V2.
Sud99 Thomas, R.C. et al. (1999) Treatment of acid mine drainage using anaerobic constructed treatment wetlands: predicting longevity with substrate neutralization potential. V2.
Sud99 Tisch, B. et al. (1999) A laboratory investigation of the potential benefit of papermill sludge as a substrate for the creation of wetlands on mine tailings. V3.

c. Natural Wetlands

568. Kleinmann,Robert LP (1800): Treatment of acid mine water by wetlands. In: Control of Acid Mine Drainage: Proceedings of a Technology Transfer Seminar. (Information Circular # 9027) (Ed: Staff,Bureau of Mines) U.S. Department of the Interior, Bureau of Mines, Unknown, 48-52.
777. Eger,P; Lapakko,K; Otterson,P (1980): Trace metal uptake by peat: Interaction of a white cedar bog and mining stockpile leachate. Proceedings of the 6th International Peat Congress in Duluth, MN, August 17-23. 542-547.
784. Lapakko,Kim; Eger,Paul; Johnson,Bruce; Loiselle,Amy (1986): Suspended solids removal from sod peat mine drainage. In: Proc. Advances in Peatlands Engineering, Carlton University, August 25-26, 1986. (:) National Research Council of Canada, Carlton University, Ottawa, 259-269.
786. Eger,Paul; Lapakko,Kim (1800): Natural wetland treatment to remove trace metals from mine drainage. Minnesota Department of Natural Resources, Division of Minerals, St. Paul, Minnesota. 22 pages.
787. Eger,Paul; Lapakko,Kim; Johnson,Bruce; Loiselle,Amy (1985): Drainage quality from a sod peat mine, first year results. In: Proc. Peat and the Environment '85 International Peat Society Symposium. (Ed: Unknown) Unknown, Jonkoping, Sweden, 317-329.
838. Nichols,DS (1985): Nutrient removal from wastewater by wetlands. Unknown Unknown, 638-642.
839. Brown,Rob G (1985): Effects of wetlands on quality of runoff entering lakes in the Twin Cities metropolitan area, Minnesota. (Water-Resources Investigations Report 85-4170) US Geological Survey and Metropolitan Council of the Twin Cities Area, St. Paul, MN. 32 pages.
1449. Spratt,Anne Kearney; Wieder,R Kelman (1988): Growth responses and iron uptake in *sphagnum* plants and their relation to acid mine drainage treatment. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 279-285.
1450. Kepler,DA (1988): An overview of the role of algae in the treatment of acid mine drainage. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 286-290.
1451. Lapakko,Kim; Eger,Paul (1988): Trace metal removal from stockpile drainage by peat. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 291-300.
1452. Eger,Paul; Lapakko,Kim (1988): Nickel and copper removal from mine drainage by a natural wetland. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 301-309.
1453. Dietz,Jonathan M; Unz,Richard F (1988): Effects of a *sphagnum* peat on the quality of a synthetic acidic mine drianage. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 310-316.

1454. Stillings,Lisa L; Gryta,Jeffrey J; Ronning,Tedd A (1988): Iron and manganese removal in a *Typa*-dominated wetland during ten months following its construction. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 317-324.

1457. Emerick,JC; Huskie,WW; Cooper,DJ (1988): Treatment of discharge from a high elevation metal mine in the Colorado Rockies using an existing wetland. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 345-352.

1706. Kwong,YTJ; Van Stempvoort,DR (1994): Attenuation of acid rock drainage in a natural wetland system. Chap. 25. In: Environmental geochemistry of sulfide oxidation. (ACS Symposium Series 550; Symposium at 204th National Meeting of the ACS, Washington, DC, Aug. 23-28) (Eds: Alpers,Charles N; Blowes,David W) American Chemical Society, Washington, DC, 382-392.

1800. Wieder,R Kelman; Lang,Gerald E (1984): Influence of wetlands and coal mining on stream water chemistry. Water, Air, and Soil Pollution 23, 381-396.

1801. Wieder,R Kelman; Lang,Gerald E; Whitehouse,Alfred E (1984): Destruction of a wetland ecosystem by inputs of circumneutral, treated coal mine drainage. In: 1984 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation. (Ed: Unknown) Unknown, Unknown, 433-441.

1804. Wieder,R Kelman; Lang,Gerald E (1985): Modification of acid mine drainage by spagnum-dominated wetlands and the effect on stream water quality. In: Wetlands of the Chesapeake: Protecting the Future of the Bay. (Ed: Unknown) US Environmental Protection Agency, Unknown, 176-184.

1805. Wieder,R Kelman; Lang,Gerald E (1986): Fe, Al, Mn, and S chemistry of sphagnum peat in four peatlands with different metal and sulfur input. Water, Air, and Soil Pollution 29, 309-320.

1806. Wieder,R Kelman; Lang,Gerald E; Whitehouse,Alfred E (1987): Treatment of acid coal mine drainage using sphagnum-dominated wetlands. In: International Workshop on Geochemistry and Monitoring in Representative Basins. (Ed: Unknown) Unknown, Unknown, 218-220. (GEOMON - Prague, Czechoslovakia, April 26- May 2)

1807. Wieder,R Kelman; Shupack,Saul I (1800): The use of wetlands to treat acid mine drainage: Growth responses of sphagnum and mechanisms of metal retention in peat. 6-month Progress Report; EPA Assistance ID No. R-812379-01-0; 13 pages.

1809. Wieder,R Kelman; Lang,Gerald E (1982): Modification of acid mine drainage in a freshwater wetland. In: Symposium on Wetlands of the Unglaciated Appalachian Region. (West Virginia University, Morgantown, WV, May 26-28) (Ed: Unknown) Unknown, Unknown, 43-53.

1810. Anonymous (1986): Cattails provide natural means of cleanup. U.S. Water News Unknown, 9.

1815. Tilton,DL (1986): Assessing the impact of wastewater discharges on wetland plant communities. Presented at Conference on Research and Applications of: Aquatic Plants for Water Treatment and Resource Recovery, Orlando, FL, July 20-24.

1837. Brenner,Fred J (1986): Evaluation and mitigation of wetland habitats on mined lands. In: 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation. (University of Kentucky, Lexington, KY, Dec 8-11) (Ed: Unknown) Unknown, Unknown, 181.

1886. Erickson,BM; Briggs,PH; Kennedy,KR; Peacock,TR (1991): Chemical composition of the wetland vegetation receiving the acid mine drainage water of St. Kevin Gulch, Leadville, CO. In: U.S. Geological Survey Toxic Substances Hydorology Program; Proceedings of the technical meeting. (Eds: Mallard,GE; Aronson,DE) U.S. Geological Survey, Tampa, FL, 419-421. (N)

2729. Nawrot,JR; Klimstra,WB; Sandusky,JE (90): Biochemical treatment of mine drainage through a reedgrass wetland. In: Proceedings 1990 Mining and Reclamation Conference and Exhibition. Vol. 2. (West Virginia University, Morgantown, WV) (Eds: Skousen,J; Sencindiver,J; Samuel,D),, 353-363.

2971. Emerick,JC; Huskie,WW; Cooper,DJ (1998): Treatment of discharge from a high elevation metal mine in the colorado rockies using an existing wetland. In: Mine Drainage and Surface Mine Reclamation. Vol. 1. (bureau of mines information circular 9183) (:) (Mine water and mine waste.) US Department of the Interior,, 341-364.

Pitt94 Brown, M.M. et al. (1994) Acid mine drainage amelioration by wetlands- Study of a natural ecosystem.V2.

Van97 Sobolewski, A. (1997) The capacity of natural wetlands to ameliorate water quality: A review of case studies. V4.
Tmw99 Pavlik, M.C. et al. (1999) Hydrogeologic controls on the geochemical function of the Forest Queen wetland, Colorado. pg 647.
Sud99 Beckett, P.J. et al. (1999) Use of catchment liming for the improvement of drainage water quality from smelter-impacted lands near Coniston, Ontario. Part 2- Changes in terrestrial and wetland components V2.
Sud99 Gunn, J.M. et al. (1999) Use of catchment liming for the improvement of drainage water quality from smelter-impacted lands near Coniston, Ontario. V2.
Sud99 Stoddern, T.J. et al. (1999) Containment of mobile metals in natural wetland systems. Studies of semi-natural wetland mesocosms with sub-surface flow. V2.

A1.2. Chemical Stabilization

a. Adsorption

161. Smith,RW; Jenne,EA (1991): Recalculation, evaluation, and prediction of surface complexation constants for metal adsorption on iron and manganese oxides. Environ. Sci. Technol. 25(3), 525-531.
181. Chapman,BM; Jones,DR; Jung,RF (1983): Processes controlling metal ion attenuation in acid mine drainage streams. Geochim. Cosmochim. Acta 47, 1957-1973.
189. Smith,KS; Ficklin,WH; Plumless,GS; Meier,AL (1992): Metal and arsenic partitioning between water and suspended sediment at mine-drainage sites in diverse geologic settings. In: Water-Rock Interation, Proceedings of the 7th International Symposium on Water-Rock Interaction-WRI-7. (Eds: Kharaka,YK; Maest,AS), Park City, Utah, 443-447.
1324. Smith,Kathleen S; Macalady,Donald L (1991): Water/sediment partitioning of trace elements in a stream receiving acid-mine drainage. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 3. (Ed: MEND Program) Quebec Mining Association, Ottawa, 435-450.
1851. Schiller,Joseph E; Tallman,Daniel N; Khalafalla,Sanaa E (1984): Mineral processing water treatment using magnesium oxide. Environmental Progress 3(2), 136-141.
2326. LeGendre,Gary R; Runnells,Donald D (1975): Removal of dissolved molybdenum from wastewaters by precipitates of ferric iron. Environ. Sci. Technol. 9(8), 744-749.
Pitt94 Norland, M.R. (1994) Fractionation of heavy metals in organically amended mine lands. V3.
Pitt94 Spotts, E.; Schafer, W.M. (1994) Determination of metal adsorption capacity of soils for stream receiving acid mine drainage.
Sud99 Ross, C.S. et al. (1999) Transport and attenuation of arsenic from a gold mine tailings impoundment. V2.
Sud99 Schulz, R.S. et al. (1999) Tailings status technology applied to up front site investigation for proposed residue storage facilities of a new gold mine. V2.

b. Encapsulation

Pitt94 Adams, R.L. et al. (1994) Laboratory testing of coatings for prevention of acid drainage in underground coal mines. V2.
Sud95 Moskalyk, R.R. (1995) Development of a protective cover for Mine waste rock. V1, 99.
Sud95 Maki, S. et al. (1995) Inhibition of pyrite oxidation by surface treatment
Sud99 Chen, Y.W. et al. (1999) Passivation of pyrite oxidation by organic compounds. V3.

Phosphate

3636. Fytas,Kostas; Evangelou,Bill (1998): Phosphate coating on pyrite to prevent acid mine drainage. International Journal of Surface Mining, Reclamation and Environment 12, 101-104.
Pitt94 Evangelou, V.P. (1994) Potential microencapsulation of pyrite by artificial inducement of $FePO_4$ coatings. V2.
Sud95 Georgopoulou, Z.J. et al. (1995) Pyrrhotite coating to prevent oxidation
Tmw99 Williams, B.C. et al. (1999) Demonstration of metals-fixation technologies on the Coeur d'Alene River, Idaho. pg 707.
Tmw99 Jensen, R. et al. (1999) Treating heavy metlas in mine soil and waste using Envirobond™ binder. pg 743.

Sud99 Roy, S.; Worral, F. (1999) Pyrite oxidation in coal-bearing strata - the use of P-blocking techniques.V1, 177.

Sud99 Conca, J.; Wright, J.; Mockler, T.J. (1999) Phosphate-induced metal stabilization for the remediation of acid Mine drainage and heavy-metal contamination. V3, 1143.

Silicate

3113 Vandiviere, M.M.; Evangelou, V.P. 1998. Comparative testing between conventional and microencapsulation approaches in controlling pyrite oxidation. J. Geochem. Exploration, 64, pg. 161-176.

3637. Zhang,YL; Evangelou,VP (1998): Formation of ferric hyroxide-silica coatings on pyrite and its oxidation. Soil Science 163(1), 53-62.

3647. Klean Earth Environmental Company (1800): Klean Earth Environmental Company. Sales Brochure.

3672. Rybock,James; Mitchell,Paul; Wheaton,Amy; Hopper,Robert (1999): Silica micro encapsulation: An innovative technology for the prevention and treatment of ARD. In: Proceedings of the Randol Gold and Silver Forum '99. (Denver, Co, May 12-14, 1999) (:),, .

3675. Chatham,WH; Svee,WA (1996): Evaluation of KEECO product KB-SEA to permanently fix arsenic and other heavy metals in mine tailings characteristic of southwest Montana. (Prepared for Bureau of Abandoned Mines, Department of Environmental Quality, State of Montana) (Phase 1 Sample characterization and batch stability tests.) University of Montana, Butte, MT. 56 pages.

3688 US EPA (1999): Environbond™ Process: Rocky Mountain Remediation Services. Superfund Innovative Technology Evaluation, Demonstration Bulletin, July, EPA/540/MR-99/502.

Tmw99 Williams, B.C. et al. (1999) Demonstration of metals-fixation technologies on the Coeur d'Alene River, Idaho. pg 707.

Sud99 Fytas, K. et al. (1999) Application of silicate coatings on pyrite to prevent acid mine drainage. V3.

c. Neutralization

567. Ladwig,Kenneth J; Erickson,Patricia M; Kleinmann,LP (1800): Alkaline injection: An overview of recent work. In: Control of Acid Mine Drainage: Proceedings of a Technology Transfer Seminar. (IC #9027) (Ed: Staff,Bureau of Mines) U. S. Department of the Interior, Bureau of Mines, Unknown, 35-40.

591. Unknown (1800): Appendix C. Screening protocols for neutralization agent. Unknown Unknown, C-1.

999. Le Roux,NW; Dacey,PW; Temple,KL (1980): The microbial role in pyrite oxidation at alkaline ph in coal mine spoil. In: Biogeochemistry of Ancient and Modern Environments. (Proc. 4th International Symposium on Environmental Biogeochemistry (ISEB) and Conference on Biogeochemistry in Relation to the Mining Industry and Environmental Pollution (Leaching Conference) in Canberra, Australia, 26 August-4 September 1979.) (Eds: Trudinger,PA; Walter,MR; Ralph,BJ) Springer-Verlag, Berlin, 515-520.

1002. Elliot,GS (1989): Pursuing nature's solutions. Mining World News 1(3), 3,17.

1003. Watzlaf,George R (1988): Chemical inhibition of iron-oxidizing bacteria in waste rock and sulfide tailings and effect on water quality. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Deparment of the Interior, Pittsburgh, 109-116.

1249. Siwik,R; Payant,S; Wheeland,K (1989): Control of acid generation from reactive waste rock with the use of chemicals. In: Tailings and Effluent Management. (Proc. International Symposium on Tailings and Effluent Management, Halifax, August 20-24) (Eds: Chalkley,ME; Conard,BR; Lakshmanan,VI; Wheeland,KG) Pergamon Press, NY, 181-193.

1524. Sturm,John W (1987): Materials handling for mine spoils and coal refuse. In: Proc. acid mine drainage seminar/workshop. (Seminar held in Halifax, Nova Scotia, March 23-26) (Ed: Environment Canada) Environment Canada, Ottawa, 321-331.

2707. Caruccio,FT; Geidel,G; Bradham,WS (1991): Accelerated pyrite oxidation/enhanced alkalinity couple to reduce acid mine drainage. Bureau of Mines, US Department of the Interior, .

2803. Lapakko,Kim (1992): Projection of the time required for neutralization potential depletion. In: Mining Exploration and the Environment '92. (Bellevue, Washington, April 6-10, 1992) (:) Society for Mining, Metallurgy, and Exploration,, .

2813. Kleinmann,Robert LP (1990): At-source control of acid mine drainage. In: Acid Mine Water in Pyritic

Environments. (Lisboa, Portugal, September, 16-19, 1990) (:),, 85-96.
2885. Michaud,LH (1995): Selective spoil placement for the prevention of acid mine drainage formation. Mining Engineering 47(March), 272-275.
2931. Beeghly,JH (1988): Blast Furnace Slag as a Liming Material for Mine Reclamation. In: Mine Drainage and Surface Mine Reclamation. Vol. Volumn II. (Information Circular 9184) (Ed: Unknown)
3528. Skousen,Jeff; Gorman,Jim; Ziemkiewicz,Paul (1999): Long term effects of two acid mine drainage remediation projects on stream quality. Green Lands (Summer), 38-44.
Pitt94 Amaratunga, L.M. (1994) Application of the novel mill tailings agglomeration technology for prevention of acid mine drainage. V2.
Pitt94 Kringel, R. (1994) Reduction of pyrite oxidation in brown coal overburden in field experiments.
Pitt94 Skousen, J.; Larew, G. (1994) Alkaline overburden addition to acid-producing materials to prevent acid mine drainage. V1.
Sud95 Jurjovec, J. et al. (1995) Acid neutralization in mill tailings and the effect of natrojarosite addition.
Sud95 Stromberg, B.; Banwart, S. (1995) Laboratory investigation of alkalinity producing reactions in sulfide containing waste rock.
Van97 Chtaini, A. et al. (1997) A study of acid mine drainage control by addition of a alkaline mill paper waste. V3.
ICD00 Morin, K.A.; Hutt, N.M. (2000) Discrete-zone mixing of net-acid-neutralizing and net-acid-generating rock: Avoiding the argument of appropriate ratios.

Class C flyash

489. Bhumbla,DK; Singh,RN; Keefer,RF (1990): Retardation of pyrite oxidation by massive fly ash application to mine spoils. In: Proceedings of the 1990 Mining and Reclamation Conference and Exhibition. Vol. 2. (Eds: Skousen,Jeff; Sencindiver,John; Samuel,Dave) Unknown, Unknown, 469.
2310. Stewart,BR; Jackson,ML; Daniels,WL (1994): The effects of fly ash blending rates and ash properties on leachate quality from fly ash/coal refuse mixtures. In: Proceedings of the International land reclamation and mine drainage conference and third international conference on the abatement of acid mine drainage, Pittsburgh, PA. Apirl 24-29, 1994. (Bureau of Mines Special Publication 06C-94) (:), Unknown, .
2471. Ziemkiewicz,Paul F; Skousen,Jeffrey G (1992): Prevention of acid mine drainage by alkaline addition. Green Lands 22, 42-51.
2597. Anonymous (1996): Penn State NMLRC -- Fighting AMD. Minelands 8(2), 9-11.
2681. Harshberger,Kevin L; Bowders,John J (1991): Acid mine drainage control utilizing fly ash. In: Energy in the Nineties. (Proceedings of a specialty conference sponsored by the Energy Diviosn of the American Society of Civil Engineers, March 10-13, 1991, Pittsburgh, PA) (Ed: Hobbs,Benjamin F) ASCE, New York, 300-305.
3088. Ashby,John C (1998): Utility byproducts used for acid mine drainage abatement at Mettiki Coal. Mining Engineering 50(December), 28-32.
Pitt94 Stewart, B.R. et al. (1994) The effects of fly ash blending rates and ash properties on leachate quality from fly ash/coal refuse mixtures. V2.

Calcareous soils

1437. Stahl,Andrew D; Parizek,Richard R (1988): A quantitative assessment of the natural abatement of acid mine drainage by interaction with Allegheny Group lithologies. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 170-179.

Lime

519. Dollhopf,Douglas J (1992): Deep Lime Incorporation Methods for Neutralization of Acid Minesoils. (RRU 9201; May, 1992) Montana State University; Reclamation Research Unit, Bozeman, MT. 94 pages.
590. Hawley,John R (1972): The Problem of Acid Mine Drainage in the Province of Ontario. Special Projects Section - Mining, Industrial Wastes Branch, Ministry of the Environment, Toronto, Ontario. 29 pages.
608. Huntington,Thomas G; Barnhisel,Richard I; Powell,James L (1980): The role of soil thickness,

subsoiling and lime incorporation methods on the reclamation of acid surface mine spoils. In: Symposium on Surface Mining Hydrology, Sedimentology and Reclamation. (Ed: University of Kentucky) University of Kentucky, Lexington, Knetucky, 9.

623. Rich,Douglas H; Hutchison,Kenneth R (1990): Neutralization and Stabilization of Combined Refuse Using Lime Kiln Dust at High Power Mountain. In: Proceedings of the 1990 Mining and Reclamation Conference and Exhibition. (Conference held April 23-26, 1990 in Charleston, West Virginia) (Ed: Unknown) Unknown, Unknown, 55-59.

925. Moss,Robert G (1987): Reclamation of abandoned mined lands on the Wayne National Forest. In: Water Resources Related to Mining and Energy-Preparing for the Future. (Ed: Dworsky,RF) American Water Resources Association, Bethesda, Maryland, 525-536.

1212. Gitt,MJ; Dollhopf,DJ (1991): Coal waste reclamation using automated weathering to predict lime requirement. J. Environ. Qual. 20(3, October), 285-288.

1333. Kuyucak,N; Sheremata,TW; Wheeland,KG (1991): Evaluation of improved lime neutralization processes - Part 1: Lime sludge generation and stability. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. (Ed: MEND Program) Quebec Mining Association, Ottawa, 1-13.

1334. Payette,C; Lam,WW; Angle,CW; Mikula,RJ (1991): Evaluation of improved lime neutralization processes - Part 2: Sludge characterization. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. (Ed: MEND Program) Quebec Mining Association, Ottawa, 15-29.

1335. Kuyucak,N; Mikula,RJ; Wheeland,KG (1991): Evaluation of improved lime neutralization processes - Part 3: Interpretation of properties of lime sludge generated by different processes. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. (Ed: MEND Program) Quebec Mining Association, Ottawa, 31-33.

1583. Iversen,Eigil; Arnesen,Rolf Tore (1988): Lime treatment of waste dumps at Kjoli Mines, Norway. Chap. 21. In: Proc. International Conference on Control of Environmental Problems from Metal Mines. (Eds: State Pollution Control Authority; Federation of Norwegian Industries) State Pollution Control Authority, Norway, 7 pages.

1645. Meek,F Allen Jr (1991): Evaluation of acid preventative techniques used in surface mining. Chap. 23. In: Environmental Management for the 1990's. (Proc. Symposium on Environmental Management for the 1990's, Denver, CO, February 25-28) (Eds: Lootens,Douglas J; Greenslade,William M; Barker,James M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 167-172.

2584. Mohamed,AMO; Boily,JF; Hossein,M; Hassanti,FP (1995): Ettringite formation in lime-remediated mine tailings I. Thermodynamic modeling. CIM Bulletin 88(995), 69-75.

2589. McBride,Stephen J; Bacheler,Norman; Yachin,Gideon; Diaz,James; Pearson,Frank (1990): Metals mitigation with crushed limestone demonstrated. Presented at EnSol 90 Conference and Exhibition, Santa Clara California, September 12-14, 1990.

2725. Nawrot,Jack R; Conley,Pat S; Sandusky,James E (1994): Concentrated alkaline recharge pools for acid seep abatement: Principles, design, construction, and performance. In: Proceedings International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of acidic drainage. Vol. 1. (Pittsburgh, PA, April 24-29, 1994, Special Publication SP 06A-94) (:) US Bureau of Mines,, 382-391.

3440. Davis,Andy; Eary,LE; Helgen,S (1999): Assessing the efficacy of lime amendment to geochemically stabilize mine tailings. Environ. Sci. Technol. 33, 2626-2632.

Pitt94 Rich, D.H.; Hutchinson, K.R. (1994) Coal refuse disposal using engineering design and lime chemistry. V1.

Pitt94 V2. Rose, A.W.; Daub, G.A. (1994) Simulated weathering of pyritic shale with added limestone and lime.

Pitt94 Tarutis, W.J.; Oram, B.F. (1994) Effect of lime addition on the leachate chemistry of a Pennsylvania coal minesoil. V2.

Sud95 Evans, D.R.; Rose, A.W. (1995) Experiments on alkaline addition to coal mine spoil.

Sud95 quality. Gunn, J.M. (1995) International experience with catchment liming for the improvement of water

Van97 Coleman, M.M.D. et al. (1997) Investigation on the placement of lime neutralization sludge on acid generating waste rock. V3.

Sud99 Gunn, J.M. et al. (1999) Use of catchment liming for the improvement of drainage water quality from smelter-impacted lands near Coniston, Ontario. V2.

ICRD00 Lapakko, K.A.; Antonson, D.A.; Wagner, J.R. (2000) Mixing of rotary kiln fines with fine-grained acid-producing rock.

Limestone/dolomite

606. Brady,Keith BC; Smith,Michael W; Beam,Richard L; Cravotta,Charles AIII (1990): Effectiveness of the addition of alkaline materials at surface coal mines in preventing or abating acid mine drainage: Part 2. Mine site case studies. In: Proceedings of the 1990 Mining and Reclamation Conference and Exhibition. (Conference held in Charleston, West Virginia (April 23-36, 1990)) (Ed: Unknown) Unknown, Unknown, 227-241.

607. Skraba,Daryll; Winterhalder,Keith (1987): The effect of applying ground limestone to the surface of acid, metal-contaminated land on groundwater and streamflow quality. In: Proceedings Ontario Chapter Canadian Land Reclamation Association. (Proceedings held in May 1987) (Ed: Unknown) Unknown, Unknown, Unknown.

609. Infanger,Michael; Hood,WC (1980): Positioning Acid-Producing Overburden for Minimal Pollution. In: Symposium on Surface Mining Hydrology, Sedimentology and Reclamation. (Ed: University of Kentucky) University of Kentucky, Lexington, Kentucky, 325.

610. Geidel,Gwendelyn; Caruccio,Frank T (1982): Acid drainage response to surface limestone layers. In: 1982 Symposium on Surface Mining Hydrology, Sedimentology and Reclamation. (Ed: University of Kentucky) University of Kentucky, Lexington, Kentucky, 403-406.

624. O'Hagan,Michael (1986): Admixing Limestone with Rocks having Low, Medium and High Sulfur Content to Mitigate Acid Mine Drainage. Masters Thesis, Department of Geology, University of South Carolina. 95 plus appendices p.

626. Burt,Ronald A; Caruccio,Frank T (1986): The effect of limestone treatments on the rate of acid generation from pyritic mine gangue. Environmental Geochemistry and Health 8(3), 71-78.

627. O'Hagan,Mike; Caruccio,Frank T (1986): The Effect of Admixed Limestone on the Rates of Pyrite Oxidation in Low, Medium, and High Sulfur Rocks. In: 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation. (Symposium held December 8-11, 1986) (Ed: University of Kentucky) University of Kentucky, Lexington, Kentucky, 155.

644. Frisbee,NM; Hossner,LR (1989): Weathering of siderite ($FeCO_3$) from lignite overburden. Paper presented at: 1989 Symposium: Reclamation a Global Perspective, Calgary, Alberta, Canada, August 27-31, 1989.

645. Brady,Keith BC; Smith,Michael W; Beam,Richard L; Cravotta III,Charles A (1990): Effectiveness of the addition of alkaline materials at surface coal mines in preventing or abating acid mine drainage: Part 2. Mine site case studies. Paper presented at: 1990 Mining and Reclamation Conference and Exhibition, Charleston, West Virginia, April 23-26, 1990, pages 227-241.

646. Cravotta III,Charles A; Brady,Keith BC; Smith,Michael W; Beam,Richard L (1990): Effectiveness of the addition of alkaline materials at surface coal mines in preventing or abating acid mine drainage: Part I. Geochemical considerations. Paper presented at: 1990 Mining and Reclamation Conference and Exhibition, Charleston, West Virginia, April 23-26, 1990, pages 221-225.

783. Lapakko,Kim; Antonson,David (1987): Status of alkaline addition experiments. (25 p. plus appendices) Minnesota Department of Natural Resources, Division of Minerals, St. Paul.

1262. Cravotta,Charles AIII; Brady,Keith BC; Smith,Michael W; Beam,Richard L (1990): Effectiveness of the addition of alkaline materials at surface coal mines in preventing or abating acid mine drainage: Part 1. Geochemical considerations. Presented at 1990 Mining and Reclmation Conference and Exhibition, Charleston, West Virginia, April 23-26.

1355. Lapakko,Kim; Antonson,David (1991): Mixing of limestone with acid producing rock. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. (Ed: MEND Program) Quebec Mining Association, Ottawa, 343-358.

2560. Anonymous (1995): Mine drainage and watersheds, Clarion, Pennslyvania. June 1-3, 1995.

2619. Anonymous (1996): Blackwater treatment a great success. Green Lands 26, 12-13. Treatment?

3049. Lapakko,Kim A; Antonson,David A; Wagner,Jon R (1998): Mixing of alkaline solids with finely-crushed acid-producing rock. Minnesota Department of Natural Resources, Division of Minerals, St. Paul, MN. 49 pages.

3345. Caruccio,Frank T (1800): The quantification of reactive pyrite by grain size. In: Unknown. (:),, 123-131.

3578. Unknown (1800): Experiments with limestone. Chap. 6. In: . (:),, .

Pitt94 Day, S.J. (1994) Evaluation of acid generating rock and acid consuming rock mixing to prevent acid rock drainage. V2.

Pitt94 Cravotta III, C.A. et al. (1994) Effects of selective handling of pyritic, acid-forming materisals on the chemistry of pore gas and ground water at a reclaimed surface coal mine, Clarion County, PA, USA. V1.

Van97 Lapakko, K.A. et al. (1997) Mixing of limestone with finely-crushed acid-producing rock. V3.

Van97 Mehling, P.E. et al. (1997) Blending and layering waste rock to delay, mitigate or prevent acid generation: A case study review. V2.

Van97 Taboada, A.G. et al. (1997) Lysimeter tests/ A method to optimize environmental forecasting the Rio Paracatu Mineracao experience. V4.

Municipal incinerator ash

Pitt94 Kim, A.G.; Ackman, T.E. (1994) Disposing of coal combustion residues in inactive surface mines: Effects on water quality. V4.

3634. Lapakko,Kim A; Antonson,David A; Wagner,Jon R (2000): Mixing of rotary kiln fines with fine-grained acid-producing rock. In: Proceedings of the Fifth International Conference on Acid Rock Drainage. (:),,

d. Phosphate

793. Hart,Walter; Stiller,Alfred; Rymer,Thomas; Renton,John (1990): The use of phosphate refuse as a potential AMD ameliorant. In: Proc. 1990 Mining and Reclamation Conference and Exhibition. Vol. 1. (Eds: Skousen,Jeff; Sencindiver,John; Samuel,Dave) Unknown, Unknown, 43-49.

794. Renton,John J; Stiller,Alfred H; Rymer,Thomas E (1988): The use of phosphate materials as ameliorants for acid mine drainage. In: Mine Drainage and Surface Mine Reclamation. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 67-75.

795. Chiado,Eric D; Bowders,John J; Sencindiver,John C (1991): Phosphatic clay slurries for reducing acid mine drainage from reclaimed mine sites. In: Proc. 1988 Mine Drainage and Surface Mine Reclamation Conference in Pittsburgh, PA, April 19-21. (Bureau of Mines Information Circular) (Ed: Unknown) United States Department of the Interior, Washington, DC, 44-51.

796. Stiller,AH; Renton,JJ; Rymer,TE (1989): An experimental evaluation of the use of phosphate (apatite) for the ameliorization of acid production, coal mine waste. West Virginia University, Department of Geology.

1250 Chiado, D.E. et al. (1988) Phosphatic clay slurries for reducing acid mine drainage from reclaimed mine sites.

1258. Stiller,AH; Renton,JJ; Rymer,TE (1800): An experimental evaluation of the use of rock phosphate (Apatite) for the ameliorization of acid producing coal mine waste. West Virginia University, Dept. Geology and Geography, Morgantown, WV.

1320. Evangelou,VP; Sainju,UM; Huang,Hiao (1991): Evaluation and quantification of armoring mechanisms of calcite dolomite and rock phosphate by manganese. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 3. (Ed: MEND Program) Quebec Mining Association, Ottawa, 363-381.

1345. Hart,Walter; Stiller,Alfred (1991): Application of phosphate refuse to coal mine refuse of amelioration of acid mine drainage. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. (Ed: MEND Program) Quebec Mining Association, Ottawa, 173-190.

Pitt94 Filipek, L.H. et al. (1994) Potential reclamation of the Brewer Pit by addition of phosphate rock. V2.

Sud99 Roy, S.; Worral, F. (1999) Pyrite oxidation in coal-bearing strata- the use of P-blocking techniques. V1.

Sud99 Conca, J. et al. (1999) Phosphate-induced metal stabilization for the remdiation of acid mine drainage and heavy metal contamination. V3.

A1.3. Physical Containment of Mine Wastes

3673. ENPAR Technologies,Inc (Ed.) (1800): Electrochemical cover to remediate acid mine drainage. ENPAR Technologies, Inc., Ontario, Canada. 7 pages.

Pitt94 St-Arnaud, L.C. et al. (1994) Mitigation of acid mine drainage by the porous envelope effect. V2.

a. Dry Covers

914. Ames,S (1979): Migration of acid substances in sullivan tailings: A column study. In: Reclaimed lands disturbed by mining. (Proc. 3rd annual British Columbia mine reclamation symposium) (Ed: Unknown) Unknown, Unknown, 309-324.

1287. Hallam,RL; Haile,JP; Brouwer,KJ (1991): Waste disposal practices for control of acidic drainage. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 4. (Ed: MEND Program) Quebec Mining Association, Ottawa, 85-106.

1297. Wilson,G Ward; Barbour,S Lee; Fredlund,Delwyn G (1991): The evaluation of evaporative fluxes from soil surfaces for the design of dry covers and the abatement of acid drainage. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 4. (Ed: MEND Program) Quebec Mining Association, Ottawa, 279-309.

1313. Lundgren,Tom; Lindahl,Lars-Ake (1991): The efficiency of covering the sulphidic waste rock in Bersbo, Sweden. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 3. (Ed: MEND Program) Quebec Mining Association, Ottawa, 239-255.

1318. Bell,Alan V; Surges,Leonard; Groskopf,Glenn R (1991): An update on the acid waste rock field trials at Heath Steele Mines, New Brunswick. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 3. (Ed: MEND Program) Quebec Mining Association, Ottawa, 319-340.

1322. Lundgren,Tom; Lindahl,Lars-Ake (1991): Remedial action programs for sulphidic wastes from ancient mining in Central Sweden. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 3. (Ed: MEND Program) Quebec Mining Association, Ottawa, 403-416.

1412 O'Kane, M. et al. (1993) Soilcover, a new computer model to aid in the design of soil cover systems for acid generating waste rock and tailings.

1442 Ackman, T.E.; Jones, J.R. (1988) Stream sealing to reduce surface water infiltration.

1547. Gale,Stephan M (1992): Reclamation of minerock stockpiles. In: Achieving land use potential through reclamation. (ASSMR9-92) (Ed: American Society for Surface Mining and Reclamation) American Society for Surface Mining and Reclamation, WV, 232.

1588. Robertson,AMacG (1988): Long term prevention of acid mine drainage. Chap. 26. In: Proc. International Conference on Control of Environmental Problems from Metal Mines. (Eds: State Pollution Control Authority; Federation of Norwegian Industries) State Pollution Control Authority, Norway, 20pages.

1590 Rasmuson, A.; Collin, M. (1988) Mathematical modelling of water and oxygen transport in layered soil covers for deposits of pyritic mine tailings.

1620. Eger,Paul; Antonson,Dave; Udoh,Francis (1990): The use of low permeability covers to reduce infiltration into mining stockpiles. Chap. 25. In: Mining and mineral processing wastes. (Proc. Western Regional Symposium on Mining and Mineral Processing Wastes, Berkeley, CA, May 30-June 1) (Ed: Doyle,Fiona M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 203-211.

1621. Caldwell,Jack A; Reith,Charles C (1990): Cover design for uranium mill tailings piles: A standard for the future. Chap. 26. In: Mining and mineral processing wastes. (Proc. Western Regional Symposium on Mining and Mineral Processing Wastes, Berkeley, CA, May 30-June 1) (Ed: Doyle,Fiona M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 213-220.

1624. Miller,Louis L; Nelson,John D; Schiffman,Robert L (1990): The impact of consolidation on the reclamation of tailings impoundments. Chap. 29. In: Mining and mineral processing wastes. (Proc. Western Regional Symposium on Mining and Mineral Processing Wastes, Berkeley, CA, May 30-June 1) (Ed: Doyle,Fiona M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 235-240.

1671. Gallinger,Ross (1988): Reclamation measures at Equity Silver Mines Limited. Chap. 11. In:

Reclamation in Changing Economic Times. (Proc. 12th Annual British Columbia Mine Reclamation Symposium) (Eds: Mining Association of British Columbia; Ministry of Energy,Mines and Petroleum Resources; Ministry of Environment) Ministry of Energy,Mines and Petroleum Resources, Victoria, BC, 121-130.

1673. Gould,Katherine L (1988): Economic strategies for reclamation at Newmont Mines Limited. Chap. 13. In: Reclamation in Changing Economic Times. (Proc. 12th Annual British Columbia Mine Reclamation Symposium) (Eds: Mining Association of British Columbia; Ministry of Energy,Mines and Petroleum Resources; Ministry of Environment) Ministry of Energy,Mines and Petroleum Resources, Victoria, BC, 139-152.

1762 Fish, W. (1993) The afterlife of solid wastes: Managing a postclosure landfill.

2121. Eger,Paul; Lapakko,Kim (1980): Stockpile leaching and chemical transport at the Erie Mining Company Dunka Site: A data summary for 1976-1979. Minnesota Department of Natural Resources-Division of Minerals, St. Paul, MN.

2122. Eger,Paul; Lapakko,Kim; Weir,Anne (1981): The environmental leaching of stockpiles containing copper-nickel sulfide minerals. Minnesota Department of Natural Resources-Division of Minerals, St. Paul, MN.

2123. Eger,Paul; Lapakko,Kim; Weir,Anne (1981): The environmental leaching of stockpiles containing copper-nickel sulfide minerals: Appendices. Minnesota Department of Natural Resources-Division of Minerals, St. Paul, MN.

2127. Gere,Eugene; Sweeney,William; Carson,Charles; Raschka,George; Olson,Orvin; Sizer,Joseph (1973): Inter-Agency Task Force Report on Base Metal Mining Impacts. Department of Natural Resources, St. Paul, MN.

2313 Anonymous (1994) Field evaluation of engineered soil covers on tailings-Waite Amulet.

2663 Manheim, F.T. (1970) The diffusion of ions in unconsolidated sediments.

2664 Rowe, R.K. et al. (1988) Laboratory determination of diffusion and distribution coefficients of contaminants using undisturbed clayey soil.

2665 Shackelford, C.D. (1991) Laboratory diffusion testing for waste disposal-A review.

2720 Anon. (1996) Evaluating cover materials for tailings deposits.

2767 Frechette, R. (1996) Reclamation cover design: Monitoring and optimization approach.

2863 O'Kane, M. et al. (1998) The design and implementation of the field test plots at BHP Iron Ore, Mt. Whaleback- A cover system for an arid climate.

2864 Benson, C.H. et al. (1994) Monitoring system for hydrologic evaluation of landfill covers.

2868. Bowerman, A.G.; Redente, E.F. (1998) In press: Biointrusion of protective barriers at hazardous waste sites.

2952. Russell,Charles WPHD (1994): Operations and Reclamation Modifications in the Landusky Mine Area. In: Mine Design, Operations & Closure Conference: Mining and the Environment. (Ed: Unknown) Zortman Mining Inc., Zortman, Montana, 1-21.

3020. Elberling,B; Nicholson,RV; Reardon,EJ; Tibbs,P (1994): Evaluation of sulphide oxidation rates: A laboratory study comparing oxygen fluxes and rates of oxidation product release. Canadian Geotechnical Journal 31(3, June), 375-383.

3238. Ribet,I; Ptacek,CJ; Blowes,DW; Jambor,JL (1995): The potential for metal release by reductive dissolution of weathered mine tailings. Journal of Contaminant Hydrology 17, 239-273.

3245. Robertson,Andy (1998): Assessment and management of risks relating to covers for metal leaching and ARD management. Chap. B14. In: Summary Notes 5th Annual BC MEM - MEND 2000 Metal Leaching and ARD Workshop -- Risk Assessment and Management. (Vancouver, British Columbia, December 9-10, 1998) (Eds: BC Ministry of Energy and Mines (BC MEM); MEND 2000 Program) BC Ministry of Energy and Mines (BC MEM), Vancouver, British Columbia.

3510. Foster,Fess (1994): Acid rock drainage management and permitting philosophy at the Golden Sunlight Mine, Whiteall, Montana. In: Mine Desing, Operations, and Closure Conference. (:),, .

3591. Swanson,Darren (1995): Letter to Kim Lapakko. Subject: Modeling of cover systems using the HELP and SoilCover Models PTI Referecne No. 0H0901.

3641. O'Kane,M; Porterfield,D; Endersby,M; Haug,MD (2000): Cover system to mitigate ARD in an arid

climate -- setup of field test plots at BHP Iron Ore's Mt. Whaleback operation. Mining Engineering 52(February), 51-56.
Sud95 Nicholson, R.V. et al. (1995) A new oxygen consumption technique to provide rapid assessment of tailings reactivity in the field and the laboratory. Pg 999.
Sud95 Swanson, D.A. et al. (1995) Modelling the performance of engineered soil covers for acid generating mine waste.
Van97 Elliott, L.C.M. et al. (1997) Evaporative losses, salt migration and mineralogical changes in dry covers over oxidized tailings. V3.
Van97 Swanson, D.A. et al. (1997) Dry-site versus wet-site cover design. V4.
Sud99 DeVos, K.J. et al. (1999) Practical considerations for covering sulfidic tailings deposits situated above the ground water table. V1.
Sud99 Garvie, A.M.; Brodie, K.M. (1999) Meaasurement of oxygen diffusion coefficients in covers on waste rock at Martha Mine, New Zealand. V1.
Sud99 Kim, H.; Benson, C. H. (1999) Oxygen transport through multilayer composite caps over mine waste. V1.
Sud99 Ritchie, D.G. (1999) A discussion of seismic design considerations for soil covers on tailings. V1.
Sud99 Wels, C. et al. (1999) A review of dry cover placement on extremely weak, compressible tailings. V2.
Sud99 Werner, K.; Berglund, S. (1999) Effects of spatial variability on oxygen transport in sulfidic mine waste deposits. V1.

Capillary Barriers

912. Rasmuson,Anders; Eriksson,Jan-Christer (1987): Capillary barriers in covers for mine tailing dumps. (Report #3307) National Swedish Environmental Protection Board, Stockholm, Sweden. 48 pages.
1131. Nicholson,Ronald V; Gillham,Robert W; Cherry,John A; Reardon,Eric J (1989): Reduction of acid generation in mine tailings through the use of moisture-retaining cover layers as oxygen barriers. Canadian Geotechnical Journal 26, 1-8.
1395 Nicholson, R.V. et al. (1991) Saturated tailings covers above the water table: The physics and criteria for design.
1396 Yanful, E.K. (1991) Engineered soil covers for reactive tailings management: Theoretical concepts and laboratory development.
1397. Yanful,EK; St-Arnaud,LC (1991): Design, instrumentation, and construction of engineered soil covers for reactive tailings management. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 487-504.
1504 Collin, M., Rasmuson, A. (1990) Mathematical modeling of water and oxygen transport in layered soil covers for deposits of pyritic mine tailings. Acid Mine Drainage: Designing for Closure, pg 311
1590. Rasmuson,Anders; Collin,Marie (1988): Mathematical modelling of water and oxygen transport in layered soil covers for deposits of pyritic mine tailings. Chap. 28. In: Proc. International Conference on Control of Environmental Problems from Metal Mines. (Eds: State Pollution Control Authority; Federation of Norwegian Industries) State Pollution Control Authority, Norway, 32pages.
2583. Bell,AV; Riley,MD; Yanful,EK (1995): Evaluation of a composite soil cover to control acid waste rock pile drainage. CIM Bulletin 88(995), 41-46.
2865 Khire, M.V. et al. (1995) Field-scale comparison of capillary and resistive landfill covers in an arid climate.
CGJ Barbour, S.L. (1990) Reduction of acid generation in mine tailings through the use of moisture-retaining cover layers as oxygen barriers: discussion. Can. Geotech. J., 27, 398-401.
CGJ Akindunni, F.F., et al. (1991) Numerical simulations to investigate moisture-retention characteristics in the design of oxygen-limiting covers for reactive mine tailings.
CGJ Yanful, E.K.; Bell, A.V.; Woyshner, M.R. (1993) Design of a composite soil cover for an experimental waste rock pile near Newcastle, New Brunswick, Canada. Can. Geotch. J., 30, 578-587.
CGJ Yanful, E.K.; Riley, M.D.; Woyshner, M.R.; Duncan, J. (1993) Construction and monitoring of a composite soil cover on an experimental waste-rock pile near Newcastle, New Brunswick, Canada. can. Geotech. J., 30, 588-599.
CGJ Elberling, B., Nicholson, R.V., Reardon, E.J., Tibble, P. (1994) Evaluation of sulfide oxidation rates: a

laboratory study comparing oxygen fluxes and ranges of oxidation product release. Can. Geotech. J., 31, 375-83.
JGE Yanful, E.K. (1993) Oxygen diffusion through soil covers on sulfidic mine tailings. J. Geotech. Eng., 119, 8, 1207-1228.
??? Anonymous (1994) Field evaluation of engineered soilcovers on tailings- waite amulet.
Pitt94 Aachib, M. et al. (1994) Column tests investigation of milling wastes properties used to build cover systems. V2.
Pitt94 Bell, A.V. et al. (1994) Evaluation for a composite soil cover to control acid waste rock pile drainage. V2.
Pitt94 Bowders, J.J. et al. (1994) Engineering evaluation of amended fly ash for hydraulic barriers. V2
Pitt94 Yanful, E.K. et al. (1994) Field and laboratory performance of engineered covers on the Waite Amulet tailings. V2.
Sud95 Bussiere, B. et al. (1995) On the use of low sulfur tailings as cover to prevent AMD: Technico-economical analysis of two case studies.
Sud95 Nicholson, R.V., Elberling, B., Williams, G. (1995) A New oxygen consumption technique to provide rapid assessment of tailings reactivity in the field and the laboratory. V3, pg 999.
Sud95 O'Kane, M. et al. (1995) Aspects on the performance of the till cover system at Equity Silver Mines Ltd.
Sud95 Puro, M.J. et al. (1995) INCO's Copper Cliff Tailings Area.
Sud95 Stuparyk, R.A. et al. (1995) Production and evaluation of los sulfur tailings at INCO's Clarabelle Mill.
Tmw97 Cabral, A. et al. (1997) Use of deinking residues as cover material in the prevention of AMD generation at an abandoned mine site.
Van97 Aubertin, M. et al. (1997) Unsaturated flow modeling of inclined layers for the analysis of covers. V2.
Van97 Aubertin, M. et al. (1997) Construction and instrumentation of in situ test plots to evaluate covers built with clean tailings. V2.
Van97 Bews, B.E. et al. (1997) The design of a low flux cover system, including lysimeters, for acid generating waste rock in semi-arid environments. V2.
Van97 Bussiere, B. et al. (1997) Effectiveness of covers built with desulfurized tailings: Column tests investigation. V2.
Van97 Cabral, A. et al. (1997) Use of deinking residues as cover material in the prevention of AMD generation at an abandoned mine site. V3.
Van97 Hanton-Fong, C.J. et al. (1997) Evaluation of low sulfur tailings in the prevention of acid mine drainage. V2.
Van97 Ricard, J.F. et al. (1997) Design and construction of a dry cover made of tailings for the closure of Les Terrains Auriferes Site, Malartic, Quebec, Canada. V4.
Van97 Tibble, P.A.; Nicholson, R.V. (1997) Oxygen consumption on sulfide tailings and tailings covers: Measured rates and applications. V2.
Van97 Wilson, G.W. et al. (1997) The cover research program at Equity Silver Mine Ltd. V1.
MEND Nicholson, R.V., Scharer, J.M., Anderson, M.E. (1997) A Rapid kinetic technique for measuring the reactivity of sulfide waste rock: the oxygen consumption method.
Tmw98 Benzaazoua, M. et al. (1998) Geochemical behavior of a multi-layered cover composed of desulfuized mine tailings.
Tmw98 Cabral, A. et al. (1998) Developments in the use of deinking residues in cover systems for acid generating mine tailings.
Tmw98 Muller, G. et al. (1998) Management of residual pyrite in mine tailings.
Tmw98 Strachan, C.L.; Raabe, K.L. (1998) Reclamation of the Panna Maria tailings impoundment:
Tmw99 Cabral, A. et al. (1999) Design construction and monitoring of a waste rock cover using pulp and paper residues. pg 405.
Sud99 Bussiere, B.; Aubertin, M. (1999) Clean tailings as cover material for preventing acid mine drainage: an in situ experiment. V1.
Sud99 Hanselman, K.; Courtin, G.M. (1999) Effect of different cover, cover/tailings mixes and capillary breaks on water dynamics within tailings and paper waste cover materials. V2.

Sud99 Ricard, J.F. et al. (1999) Performance of a dry cover made of tailings from the closure of Les Terrains Auriferes site, Malartic, Quebec, Canada. V1.

Clay

1313 Lundgren, T.; Lindahl, L.A. (1991) The efficiency of covering the sulfidic waste rock in Bersbo, Sweden.

1424 Murray, E.W. et al. (1988) Laboratory and field testing of a salt-supplemented clay cap as an impermeable seal over pyritic slates.

2866 Udoh, F.D. (1993) Minimization of infiltration into mining stockpiles using low permeability covers. PhD thesis.

Pitt94 Yanful, E.K.; Shikatani, K.S. (1994) Sand-bentonite mixture as a cover for managing reactive mine wastes. V2.

Sud95 Yanful, E.K.; Shikatani, K.S. (1995) Compatibility of a sand-bentonite mixture with ARD.

Tmw97 Williams, D.J. et al. (1997) A cover system for a potentially acid forming waste rock dump in a dry climate.

Van97 Aziz, M.L.; Ferguson, K.D. (1997) Equity Silver Mine- Integrated case study. V1.

Van97 Lindvall, M. et al. (1997) The reclamation project at Saxberget Mine, Sweden. V3.

Van97 Lundgren, T. (1997) Bersbo Pilot Project- Physical behavior seven years after covering the waste rock piles. V3.

Van97 Woyshner, M.R. et al. (1997) Five years after covering tailings and waste rock with a composite soil cover: A case review and water quality predictions at the Millenbach site near Rouyn-Noranda, Quebec. V4.

Tmw98 Owaidat, L.W.; Day, S.R. (1998) Installation of a composite slurry wall to contain mine tailings

Geosynthetic Clay Liners (GCLs)

Tmw97 Stewart, D. vonMaubeuge, K. (1997) Cost effective and efficient solutions with geosynthetic clay liners for sealing applications in the mining industry.

Tmw98 Brennecke, D.F.; Corser, P.G. (1998) Performance issues related to geosynthetic liners at Monticello, Utah.

Tmw98 Miller, B.; Hornaday, C. (1998) Geosynthetic clay liners for the mining industry.

Tmw98 Sevick, G.W. et al. (1998) Engineered upland sulfide tailings management facility.

Tmw99 Miller, B. (1999) Case studies on the use of geosynthetic clay liners in mining reclamation. pg 353.

Tmw99 Brewer, W. et al. (1999) Construction quality assurance of a geosynthetic clay liner at high elevation. pg 359.

Geotextile Liners

1676. Williams,Brian (1989): Use of geotextile products in water control. Chap. 3. In: Water Management at Minesites. (Proc. 13th Annual British Columbia Mine Reclamation Symposium) (Eds: Mining Association of British Columbia; Ministry of Energy,Mines and Petroleum Resources; Ministry of Environment) Ministry of Energy,Mines and Petroleum Resources, Victoria, BC, 27-36.

2524 Cadwaller, M.W. (1800) Cost effective tailings pond and heap leach pad liners: a case history.

Tmw97 Thornton, C.I. et al. (1997) Riprap rock durability versus rock qualtiy: A case study.

Tmw98 Neukirchner, R.J.; Lord, G.G. (1998) Covering of soft mine tailings.

Tmw98 Shuri, F.S. et al. (1998) Design of the tailings disposal facilities for Battle Mountain Gold Company's Crown Jewel Mine near Oroville, Washington.

Tmw99 Thomas, R.W. (1999) Industry activities for improving material and installation specifications for geomembranes. pg 367.

Sud99 Lewis, B.A.; Gallinger, R.D. (1999) Poirier site reclamation program. V2.

Grouts

Suspension grouts (Portland cement, clay, cement-clay)

1272. Norwest Geochem (1992): Shotcrete application of cementitious sealant materials for acid rock drainage control. International Mine Waste Management News 2(2), 11.

1286. Gerencher,EH; Wong,JY; Van Dyk,R; Konasewich,DE (1991): The use of mine tailings in concrete surface covers to control acid mine drainage in waste rock dumps. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 4. (Ed: MEND Program) Quebec Mining

Association, Ottawa, 69-84.
1313 Lundgren, T.; Lindahl, L.A. (1991) The efficiency of covering the sulfidic waste rock in Bersbo, Sweden.
1398. Malhotra,VM (1991): Fibre-reinforced high-volume fly ash shotcrete for controlling aggressive leachates from exposed rock surfaces and mine tailings. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 505-513.
Pitt94 Jones, C.E.; Wong, J.Y. (1994) Shotcrete as a cementitious cover for acid generating waste rock piles. V2.
Sud95 Moskalyk, R.R. (1995) Development of a protective cover for mine waste rock.
Sud95 Scheetz, B.E. et al. (1995) Field applications of cementitious grouts to address the formation of acid mine drainage.
Tmw97 Zou, D.H.S. (1997) An innovative technology for tailings treatment.
Van97 Lundgren, T. (1997) Bersbo Pilot Project- Physical behavior seven years after covering the waste rock piles. V3.

Chemical grouts (alkali silicates, organic polymers)
Bituminous grouts (bitumen/water, heated bitumen, bitumen mixtures)
Other grouts (lignochrome, furan, other polymers)
Gel grouts (acrylic)

Hardpans

2716 Ahmed, S.M. (1995) Chemistry of pyrrhotite hardpan formation.
2745 Chermak, J.E.; Runnells, D.D. (1997) Development of chemical caps in acid rock drainage environments.
Pitt94 Ahmed, S.M. (1994) Surface chemical methods of forming hardpan in pyrrhotite tailings and prevention of the acid mine drainage. V2.
Twm97 Lin, Z.; Herbert, R.B. Jr. (1997) Formation of Fe precipitated layers in a mill-tailings deposit: Barriers to metal mobilization.
Van97 Tasse, N. et al. (1997) Hard-pan formation in the Canadian Malartic mine tailings: Implication for the reclamation of the abandoned impoundment. V4.
Tmw99 Ettner, D.C.; Braastad, G. (1999) Induced hardpan formation in a historic tailings impoundment, Roros, Norway. pg 457.
Bill00 Shay, D.A.; Cellan, R.R. (2000) Acid remediation at Homestanke's Santa Fe Mine using a chemical cap. Proc. 2000 Billings Land Reclamation Symposium, March 20-24, Billings, MT. CD-ROM

Organic

1589 Michelutti, R.E. (1988) Minimizing metal contaminated seepages from high sulfide tailings by establishing a marsh cover.
1719. Tasse,N; Germain,MD; Bergeron,M (1994): Composition of interstitial gases in wood chips deposited on reative mine tailings. Chap. 38. In: Environmental geochemistry of sulfide oxidation. (ACS Symposium Series 550; Symposium at 204th National Meeting of the ACS, Washington, DC, Aug. 23-28) (Eds: Alpers,Charles N; Blowes,David W) American Chemical Society, Washington, DC, 631-644.
Pitt94 Pierce, W.G. et al. (1994) Composted organic wastes as anaerobic reduction covers for long term abandonment of acid-generating tailings. V2.
Pitt94 Tremblay, R.L. (1994) Controlling acid mine drainage using an organic cover: The case of the East Sullivan Mine, Abitibi, Quebec. V2.
Sud95 Stogran, S.W.; Wiseman, M.E. (1995) A comparison of organic and inorganic covers for long term prevention or amelioration of acid mine drainage.
Tmw97 Elliott, L.C.M. et al. (1997) Evaluation of single layer organic and inorganic cover materials for oxidized tailings.
Van97 Chtaini, A. et al. (1997) A study of acid mine drainage control by addition of a alkaline mill paper waste. V3.
Van97 Delaney, T. et al. (1997) Applications of method for delaying the onset of acidic drainage. V2.

Van97 Elliott, L.C.W. et al. (1997) Organic cover materials for tailings: Do they meet the requirements of an effective long term cover? V2.
Van97 Tasse, N. et al. (1997) Organic-waste cover over the East Sullivan Mine tailings: Beyond the oxygen barrier. V4.
Sud99 Tasse, N. (1999) Long term efficiency of wood waste covers: indications from pore gases compositions. V2.

Self-Sealing/Self-Healing Systems

Van97 McGregor, R.G. et al. (1997) Preliminary results of a field study of a self-sealing/self-healing cover system. V3.

Sludge

1399. Broman,Per G; Haglund,Per; Mattsson,E (1991): Use of sludge for sealing purposes in dry covers--Development and field experiences. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 515-527.

Soils

166 Phelps, L.B.; Holland, L.(1987) Soil compaction in topsoil replacement during mining reclamation. Environ. GC & Health: Incorporating Minerals and the Environment. 8-11.
781 Eger, P. et al. (1990) Stockpile capping report.
1397 Yanful, E.K.; St-Arnaud, L.C. (1991) Design, instrumentation, and construction of engineered soil covers for reactive tailings management.
2075 Beers, W.F. et al. (1974) Soil as a medium for the renovation of acid mine drainage water.
2583 Bell, A.V. et al. (1995) Evaluation of a composite soil cover to control acid waste rock pile drainage.
2727 Nawrot, J.R.; Smout, G. (1993) The new Katheleen Mine- Soil covered refuse demonstration: 20 year later.
2728 Nawrot, J.R. et al. (1991) Soil cover and alkaline amendment alternatives for coal slurry impoundments.
2866 Udoh, F.D. (1993) Minimization of infiltration into mining stockpiles using low permeability covers. PhD thesis.
3492. Vipulanandan,C; Krizek,RJ (1983): Quality of runoff water from soil-covered reclamation sites. In: Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation. (Eds: Graves,Donald H; DeVore,R William) University of Kentucky, Lexington, Kentucky, 225-232.
3497. Smout,GA; Sobek,AA (1983): New Kathleen: Ten years after reclamation by soil emplacement over coarse coal refuse. In: Symposium on Mining, Hydrology, Sedimentology, and Reclamation. (Eds: Graves,Donald H; DeVore,R William) University of Kentucky, Lexington, Kentucky, 515.
Sud95 McGinness, S. et al. (1995) Stability of industrial mineral soil amendments subject to biological degradation.
Tmw97 McLendon, T. et al. (1997) The inclusion of biointrusion considerations in the design of the reclamation cover for the DMC tailings impoundments.
Van97 Gardiner, R.T. et al. (1997) Application of ARD abatement technology in reclamation of tailing ponds at Cominco Ltd., Sullivan Mine. V1.
Van97 Woyshner, M.R.; Swarbrick, B. (1997) First year findings from soil cover test plots on Kidd Creek thickened tailings near Timmins, Ontario. V3.
Tmw98 Kowalewski, P.E. et al. (1998) Tailings impoundment reclamation soil cover design at the Ridgeway Mine.
Tmw99 Boldt-Leppin, B. et al. (1999) Soil covers for sloped surfaces of mine waste rock and tailings. pg. 393.
Tmw99 Newman, L.L. et al. (1999) Alligator Ridge tailings impoundment closure: A 100-yr performance of a soil cover. pg 417.

b. Wet Covers

1269. Flather,David (1992): Subaqueous disposal of mine wastes. Part 1 of 3. International Mine Waste Management News 2(2, April), 5-6.
1378. Deopker,Richard D; Drake,Pamela L (1991): Laboratory study of submerged metal-mine tailings 3: Factors influencing the dissolution of metals. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 139-155.

1394 Ritcey, G.M. (1991) Deep water disposal of pyritic tailings - A simulation for acid prediction. 2nd Internat. Conf. on the Abatement of Acidic Drainage, Montreal, Quebec. V1, 421-442.

1417. Morin,Kevin A (1993): Rates of sulfide oxidation in submerged environments: Implications for subaqueous disposal. In: Proc. 17th Annual British Columbia Mine Reclamation Symposium: Mine Reclamation "Building Confidence". (Ed: Sponsored by: Mining Association of British Columbia) The Ministry of Energy, Mines and Petroleum Resources, British Columbia, 235-247.

1836 Maynard, A.W.; Thomas, K.B. (1994) A laboratory quality assurance component of environmental monitoring: A case study involving subaqueous tailings research. V1.

2633. Salazar,Rogelio C; Gonzales,Reynaldo I (1973): Design, construction, and operation of the tailings pipelines and underwater tailings disposal system of Atlas Consolidated Mining and Development Corporation in the Phillippines. In: International Tailing Symposium. first ed. (Ed: Freeman), San Francisco, CA, .

2640. Rescan Environmental Services,Ltd (1989): Subaqueous disposal of reactive mine wastes: An overview. Rescan Environmental Services, Ltd., Vancouver, Canada. 107 pages.

2662. Schuring,J; Kolling,M; Sculz,HD (1997): The potential formation of acid mine drainage in pyrite-bearing hard-coal tailings under water-saturated conditions: An experimental approach. Environmental Geology 31(1-2), 59-65.

2719 Lapakko, K.A. (1994) Subaqueous disposal of mine waste: Laboratory investigation. V1.

2721 Anon (1996) Water covers for prevention of acid generation.

2756. Rescan Environmental Services Ltd. (Ed.) (1989): Subaqueous disposal of reactive mine wastes: An overview. Rescan Environmental Services Ltd., Vancouver, Canada. 175 pages.

2786 Yanful, E.K.; Simms, P. (1996) Review of water cover research and application.

2867. Schuring,J; Kolling,M; Schultz,HD (1997): The potential formation of acid mine drainage in pyrite-bearing hard-coal tailings under water-saturated conditions: an experimental approach. Environmental Geology 31(1/2), 59-65.

3449. Unknown (Ed.) (1997): Fourth International Conference on Acid Rock Drainage. (Short Course #1: Water Covers and Underwater Disposal to Prevent AMD, Vancouver, BC, May 31-June 6, 1997), .

3451. Morin,Kevin A (1993): Rates of sulfide oxidation in submerged environments: Implications for subaqueous disposal. In: Proceedings of the Seventeenth Annual British Columbia Mine Reclamatiom Symposium. (:) The Ministry of ENergy, Mines, and Petroleum Resources, British Cloumbia, Canada, 235-247.

3453 MEND (1997) Workshop notes: Water covers and underwater disposal to prevent ARD. Vancouver, British Columbia. MEND Program.

3458 Aube, B.C. et al (1995) Laboratory evaluation of the effectiveness of water covers for preventing acid generation from pyritic rock.

3459 Stogran, S.W.; Wiseman, M.E. (1995) Technical evaluation of subaqueous disposal of alkaline, unoxidized, sulfide containing tailings in acidic water.

3461 St-Arnaud, L. (1994) Water covers for the decommissioning of sulfidic mine tailings impoundments. V1.

3464 Doepker, R.D.; Drake, P.L. (1991) Laboratory study of submerged metal-mine tialings 3: Factors influencing the dissolution of metals. 2nd Internat. Conf. on the Abatement of Acidic Drainage, Montreal, Quebec. V1, 139-155.

Pitt94 Domvile, S. et al. (1994) Laboratory modelling of subaqueous disposal environments.V2.

Pitt94 Filion, M.P. et al. (1994) Regulatory controlled design-Louvicourt Project-A case study. V2.

Sud95 Martel, R.L.; Dickson, A. (1995) Implementation of a remediation plan for the abandoned Sturgeon Lake property.

Sud95 Payant, S. et al. (1995) Evaluation of techniques for preventing acidic rock drainage.

Sud95 Quarshie, L.; Rowson, J. (1995) Waste rock leach tests at the Cluff Mining operation in northern Saskatchewan.

Sud95 Tisch, B.; Winterhalder, K. (1995) Leaching column studies to explore the potential of waste materials as closeout covers for copper-zinc tailings at Timmins, Ontario.

Van97 Jones, D.R. et al. (1997) Evaluating close-out options for acid generating tailings. V3.

Van97 Mugo, R.K. et al. (1997) A predictive quantitative geochemical assessment of the subaqueous stability of acid-generating mine tailings. V1.
Van97 Stogran, S.W. et al. (1997) Subaqueous deposition of acid generating tailings into an acidic environment: Pilot column test results. V3.
Sud99 Mugo, R.K. et al. (1999) Subaqueous tailings disposal in freshwater and marine environments-results of predictive geochmical testing using tailings with different compositions. V1.
Sud99 Nicholson, R.V. et al. (1999) Assessment of water quality associated with underwater disposal of tailings and waste rock from the Voisey's Bay Project, Labrador, Canada. V1.

Flooding tailings basins

1128. Sheremata,TW; Yanful,EK; St-Arnaud,LC; Payant,SC (1991): Flooding and lime addition for the control of acidic drainage from mine waste rock: A comparative laboratory study. Presented at the First Canadian Conference on Environmental Geotechnics, Canadian Geotechnical Society, Montreal, May 14-16.
1303 Dave, N.K.; Michelutti, R.E. (1991) Field evaluation of wet cover alternatives of high sulfide tailings.
1392 Balins, J.K.; Welch, D.E. (1991) Decommissioning of the Quirke Mine uranium tailings basin to eliminate acid production. 2nd Internat. Conf. on the Abatement of Acidic Drainage, Montreal, Quebec. V3, 379-397.
2723. St-Arnaud,Luc C; Yanful,Ernest K (1993): Water covers for the decommissioning of sulphidic mine tailings impoundments: Mattabi mines case study. In: Proceedings CIM Conference of Metallurgists/Advances in Environmental Protection for Metallurgical Industries. (:),, .
2724. Boyd,Timothy J (1993): Control of ARD using subaqueous deposition of mine tailings. In: Proceedings MMPE 590 ARD Symposium. (April 13, 1993) (:),, .
2737 Nawrot, J.R. et al. (1984) Enhancing reclamation through selective slurry disposal.
2738 Nawrot, J.R. (1981) Stabilization of slurry impoundments without soil cover: Factors affecting vegetation establishment.
2755 Dave, N.K. (1992) Water cover on acid generating mine/mill wastes: A technical review.
2860. Beckett,Peter; Willianen,Sharon Pappin; Vivyurka,Albert J; Courtin,Gerard (1997): Establishment of deep water aquatic plants in permanently flooded pyritic uranium tailings - A field test. Presented at Fourth International Conference on Acid Rock Drainage, Vancouver, BC, Canada, June 1997.
2862. Lawrence,GA; Ward,PRB; MacKinnon,MD (1991): Wind-wave induced suspension of mine talings in disposal ponds. Canadian Journal of Civil Engineering 18(6), 1047-1053.
3450. Dave,Nand K; Lim,TP; Horne,D; Boucher,Y; Stuparyk,Rodney (1997): Water cover on reactive tailings and wasterock: Laboratory studies of oxidation and metal release characteristics. In: Fourth International Conference on Acid Rock Drainage. Vol. II. (:),, 779-794.
3478. Campbell,PGC; Roy,R (1993): Literature Review: Possible Means of Evaluating the Biological Effects of Sub-Aqueous Disposal of Mine Tailings. INRS-EAU, Quebec, Canada. 54 plus appendices pages.
Pitt94 Balins, J.K. et al. (1994) Probabilistic assessment of the long-term performance of the Panel Mine tailings area. V2.
Pitt 94 Broman, P.G.; Goransson, T. (1994) Decommissioning of tailings and waste rock areas at Stekenjokk, Sweden. V2
Van97 Amyot, G.; Vezina, S. (1997) Flooding as a reclamation solution to an acidic tailing pond: The Solbec case. V2.
Van97 Arnesen, R.T. et al. (1997) Comparison of model predicted and measured copper and zinc concentrations at three Norwegian underwater tailings disposal sites. V4.
Van97 Atkins, R.J. et al. (1997) Shallow water cover design methodology and field verification. V1.
Van97 Aubertin, M. et al. (1997) Design guidelines and stability criteria of engineering works for water covers. V4.
Van97 Kam, S.N. et al. (1997) Interim assessment of flooded tailings performance: Quirke Mine waste management area. V2.
Van97 Li, M.G. et al. (1997) Considerations in the use of shallow water covers for decommissioning reactive tailings. V1.

Van97 Ljungberg, J. et al. (1997) Geochemical field study of flooded mine tailings at Stekenjokk, Northern Sweden. V3.
Van97 Robertson, J.D. et al. (1997) Subaqueous tailing disposal: A sound solution for reactive tailing. V3.
Van97 Robertson, W.D. et al. (1997) Sulfide oxidation related to water table depth at two Sudbury, Ontario tailings impoundments of differing physiography. V2.
Van97 St-Germain, P. et al. (1997) Field studies of biologically supported water covers at two Noranda tailings ponds. V1.
Tmw99 Evans, A. Jr. (1999) Wet closure of exposed tailings using surficial lime slurry application. pg 485.
Sud99 Beckett, P.J. et al. (1999) Wetland plant establishment and growth in tailings engineered with water covers. V2.
Sud99 Lindvall, M. et al. (1999) Decommissioning at Kristineberg mine, Sweden. V3.
Sud99 Paktunc, A.D.; Dave, N.K. (1999) Acidic drainage characteristics and residual sample mineralogy of unsaturated and saturated coarse pyritic uranium tailings. V1.
Sud99 Zou, D.H.S.; Huang, Y. (1999) A proposed method of underwater capping for tailings disposal. V2.

Flooding underground mines

1128 Sheremata, T.W. et al. (1991) Flooding and lime addition for the control of acidic drainage from mine waste rock: A comparative laboratory study.
1311. Arnesen,RT; Iversen,ER; Kallqvist,ST; Laake,M; Lien,T; Christensen,B (1991): Monitoring water quality during filling of the Lokken Mine: A possible role of sulfate-reducing bacteria in metals removal. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 3. (Ed: MEND Program) Quebec Mining Association, Ottawa, 201-217.
Pitt94 Aljoe, W.W. (1994) Hydrologic and water quality characteristics of a partially-flooded, abandoned underground coal mine. V2.
Van97 Arnesen, R.T.; Iversen, E.R. (1997) The 'Lokken Project'- Flooding a sulfide ore mine. V3.
Van97 Neukirchner, R.J.; Hinrichs, D.R. (1997) Effects of ore body inundation- A case study. V4.
Tmw98 Hockley, D. et al. (1998) Estimating contaminant concentrations in a re-flooded underground mine.

Lakes

1285 Liseth, P.; Miljoplan, V. (1991) Abatement measures for the acid mine drainage at Skorovas Mine, Norway. 2nd Internat. Conf. on the Abatement of Acidic Drainage, Montreal, Quebec. 43-68.
1293 Pedersen, T.F.; Mueller, B.; McNee, J.J. (1991) Diagenetic reactivity of mine tailings in mesotrophic and oligotrophic lakes in Manitoba and British Columbia. 2nd Internat. Conf. on the Abatement of Acidic Drainage, Montreal, Quebec. V4, 199-226.
1310 Robertson, J.D. (1991) Subaqueous disposal of reactive mine waste: An overview of the practice with case studies. 2nd Internat. Conf. on the Abatement of Acidic Drainage, Montreal, Quebec., V3, 185-200.
1502. Pedersen,Thomas F; Mueller,Bert; Pelletier,Clem A (1990): On the reactivity of sumberged mine tailings in Fjords and a lake in British Columbia. In: Acid mine drainage: Designing for closure. (Presented at GAC/MAC Joint Annual Meeting in Vancouver, May 16-18) (Eds: Gadsby,John W; Malick,James A; Day,Stephen J) BiTech Publishers Ltd., Vancouver, BC, 285-293. (N)
1503. Dave,Nand K; Lim,Tjoe P; Vivyurka,Albert J; Bihari,Biman; Kay,David A (1990): Development of wet barriers on pyritic uranium tailings Elliot Lake, Ontario: Phase I. In: Acid mine drainage: Designing for closure. (Presented at GAC/MAC Joint Annual Meeting in Vancouver, May 16-18) (Eds: Gadsby,John W; Malick,James A; Day,Stephen J) BiTech Publishers Ltd., Vancouver, BC, 295-310.
1577. Arnesen,Rolf Tore; Grande,Magne; Iversen,Eigil (1988): Tailings disposal from Grong Gruber A/S under water in Lake Huddingsvatn. Chap. 14. In: Proc. International Conference on Control of Environmental Problems from Metal Mines. (Eds: State Pollution Control Authority; Federation of Norwegian Industries) State Pollution Control Authority, Norway, 14 pages.
2312. Anonymous (1994): Control of amd at panel site, Elliot Lake. MEND Newsletter 2(1, March), 2.
3455 Stevens, C.L.; Lawrence, G.A. (1997) The effect of sub-aqueous disposal of mine tailings in standing waters. J. Hydraulic Res., 35, 2, 147-159.
3460 Fraser, W.W.; Robertson, J.D. (1994) Subaqueous disposal of reactive mine waste: An overview and

update of case studies- MEND/Canada. V1.
3462 Pedersen, T.F. et al. (1994) Geochemistry of submerged tailings in Anderson Lake, Manitoba: Recent results. V1.
3463 Dave, N.K.; Vivyurka, A.J. (1994) Water cover on acid generating uranium tailings-Laboratory and field studies.
Van97 Pedersen, T.F. et al. (1997) Geochemistry of submerged tailings in Buttle Lake and the Equity Silver tailings pond, British Columbia and Anderson Lake, Manitoba: What have we learned? V3.
Sud99 Pedersen, T.F. et al. (1999) Contrasting trace metal dynamics in contaminated Lago Junin, Peru and submerged tailings deposits in Canadian lakes: the importance of permanent submergence. V1.

Marine disposal

2722. Drake,Pamela L; Lambeth,Robert H; Paulson,Anthony J (1995): Metal release characteristics of tailings in a marine environment: A laboratory study. In: 1995 National Meeting of the American Society for Surface Mining and Reclamation. (Gillette, WY, June 5-8, 1995) (:) ASSMR,, 1-15.
2830. Ellis,DV; Poling,GW; Baer,RL (1995): Submarine tailings disposal (STD) for mines: An introduction. Marine Georesources and Geotechnology 13, 3-18.
2831. Garnett,RHT; Ellis,DV (1995): Tailings disposal at a marine placer mining operation by WestGold, Alaska. Marine Georesources and Geotechnology 13, 41-57.
2832. Ellis,DV; Pedersen,TF; Poling,GW; Pelletier,C; Horne,I (1995): Review 23 years of STD: Isalnd Copper Mine, Canada. Marine Georesources and Geotechnology 13, 59-99.
2833. Poling,GW; Ellis,DV (1995): Importance of geochemistry: The Black Angel lead-zinc mine, Greenland. Marine Georesources and Geotechnology 13, 101-118.
2834. Pedersen,TF; Ellis,DV; Poling,GW; Pelletier,C (1995): Effects of changing environmental rules: Kitsault molybdenum mine, Canada. Marine Georesources and Geotechnology 13, 119-133.
3456 Rankin, M. et al. (1997) Submarine tailings discharge: Optimizing the evaluation and monitoring process.

Open pits

486. Naugle,GD; Atkinson,LC (1993): Estimating the rate of post-mining filling of pit lakes. Mining Engineering 45(4, April), 402-404.
1312 Veillette, G.; Desrochers, C.J. (1991) Reclamation of the Solbec Mine site by flooding waste rock in open pit. 2nd Internat. Conf. on the Abatement of Acidic Drainage, Montreal, Quebec. V3, 219.
1393 St-Arnaud, L.C.; Aiken, S.R. (1991) Hydrogeology and geochemistry of the Brunswick Mining No. 6 open pit mine site. 2nd Internat. Conf. on the Abatement of Acidic Drainage, Montreal, Quebec. V3, 399-420.
2759. MEND Treatment and Technology Transfer Committees; SENES Consultants Limited; Wheeland,Ken (Eds.) (1995): Review of in-pit disposal practices for the prevention of acidic drainage -- case studies. SENES Consultants Limited, Richmond Hill, Ontario. 175 pages.
3083. Jakel,Emmelyn; Lapakko,Kim; Berndt,Mike (1998): Taconite tailings in-pit disposal field tank experiments: Data summary June 1998. Minnesota Department of Natural Resources, Division of Minerals, St. Paul, MN. 37 plus appendices pages.
3452 SENES Consultants Ltd. (1995) Review of in-pit disposal practices for the prevention of acid drainage - Case studies. MEND Report # 2.36.1,
Pitt94 Feasby, D.G. et al. (1994) International perspective on the role of acid generation in selecting decommissioning techniques for uranium mining sites in Eastern Germany. V2.
Tmw97 Meyer, W.A. et al. (1997) Suppression of sulfide mineral oxidation in mine pit walls. Part 2. Geochemical modeling.
Tmw97 Warren, G.C. et al. (1997) Suppression of sulfide mineral oxidation in mine pit walls. Part 1. Hydrologic modeling.
Van97 Atkins, D. et al. (1997) Limnologic conditions in three existing Nevada Pit Lakes: Observations and modeling using CE-QUAL-W2. V2.
Van97 Bursey, G.G. et al. (1997) Approach used to model pit filling and pit lake chemistry on mine closure-Voisey's Bay, Labrador. V1.
Van97 Hamblin, P.F. et al. (1997) Vertical transport in Brenda Mines Pit Lake. V1.

Van97 Orava, D.A. et al. (1997) Prevention of acid rock drainage through the application of in-pit disposal and elevated water table concepts. V3.

Tmw99 Dorey, R. et al. (1999) Open pit reclamation at the Kennecott Ridgeway gold mine. pg 701.

A1.4. Surface Reclamation for Revegetation

166. Phelps,L Barry; Holland,Lysa (1987): Soil compaction in topsoil replacement during mining reclamation. Environmental Geochemistry and Health: Incorporating Minerals and the Environment, ISSN 0269-4042 9(1), 8-11.

556. Apel,M Lynn (1982): Leachability and Revegetation of Solid Waste from Mining. (EPA-600/2-82-093) Industrial Environmental Research Laboratory: Office of Research and Development: U.S. Environmental Protection Agency, Cincinnati, Ohio.

778. Eger,P; Sturgess,J; Lapakko,K (1980): The leaching and revegetation of low-grade mineralized stockpiles: A status report. (Presented at the AIME Annual Meeting in Las Vegas, Nevada, February 24-28) Society of Mining Engineers of AIME, Littleton, CO. 11 pages. (Preprint Number 80-80)

781. Eger,Paul; Antonson,Dave; Udoh,Francis (1990): Stockpile capping report. Minnesota Department of Natural Resources, Division of Minerals, St. Paul, MN. 47 pages.

918. Rieger,Nick (1988): Revegetation of agglomerated heap leach ore. 1988 Symposium on Mining, Hydrology, Sedimentology and Reclamation, University of Kentucky, Lexington, KY, December 5-9.

921. Anderson,JE (1980): Mine dump vegetation: Practice and problems. In: Biogeochemistry of Ancient and Modern Environments. (Proc. 4th International Symposium on Environmental Biogeochemistry and Conference on Biogeochemistry in Relation to the Mining Industry and Environmental Pollution, Canberra, Australia 26 August-4 September 1979) (Eds: Trudinger,PA; Walter,MR; Ralph,BJ) Springer-Verlag, Berlin Heidelberg NY, 713-717.

922 Craze, B. (1980) Mine waste pollution control at captains flat, New South Wales.

1179. Gilman,Edward F; Flower,Franklin B; Leone,Ida A (1983): Project Summary: Standarized Procedures for Planting Vegetation on Completed Sanitary Landfills. (S2-83-055) U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati,OH. 3 pages.

1532. Veldhuizen,H; Blowes,DW; Siwik,RS (1987): The effectiveness of vegetation in controlling acid generation in base metal tailings. In: Proc. acid mine drainage seminar/workshop. (Seminar held in Halifax, Nova Scotia, March 23-26) (Ed: Environment Canada) Environment Canada, Ottawa, 507-536.

1723. Erickson,Patricia M; Campion,Peter SA (1982): Reducing oxidation of pyrite through selective reclamation practices. In: 1982 Symposium on surface mining, hydrology, sedimentology, and reclamation. (University of Kentucky, Lexington, KY, December 5-10) (Eds: Graves,Donald H; DeVore,R William) University of Kentucky, Lexington, KY, 97-102.

2621. Schafer,William M; Babits,Margaret (1987): Lime and tillage effects on soil copper and zinc partitioning and vegetative response in acid contaminated agricultural soils in southwestern Montana. In: Proceedings of 1987 National Meeeting of American Society for Surface Mining and Reclamation and Fourth Biennial Symposium on Surface Mining and Reclamation on the Great Plains. (Report No. 8704) (Ed: Montana State University Reclamation Research Unit),, 277-287.

2736. Nawrot,JR; Warburton,DB; Klimstra,WB (1986): Coarse refuse reclamation: Alkaline enhancement for direct vegetation establishment. In: The National Mines Land Reclamation Conference. (St. Louis, MO, October 28-29, 1986) (:),, 613-636.

3495. Lee,CR; Skogerboe,JG; Brandon,DL; Linkinhoker,JW; Faulkner,SP (1983): Vegetative restoration of pyritic soils. In: Symposium on Mining, Hydrology, Sedimentology, and Reclamation. (Eds: Graves,Donald H; DeVore,R William) University of Kentucky, Lexington, Kentucky, 271-282.

Pitt94 Dewar, S.W.; Norland, M.R. (1994) Growth and trace metal content of poplars planted on tailing treated with municipal solid waste compost.

Pitt94 V3 Melchert, G.D. et al. (1994) Reclaiming coarse taconite tailings with municipal solid waste compost.

Tmw97 Smith, G.M. et al. (1997) Analog of the long-term performance of vegetated rocky slopes for landfill covers.

Sud99 Feng, Y. et al. (1999) Assessing the suitability of paste as a medium for plant growth. V3.
Sud99 Meikle, T.W. et al., (1999) Identifying reclamation strategies: Waste rock as a growth substrate. V2.
Sud99 Mulligan, D. et al. (1999) Reconstruction of sustainable ecosystems on mined lands in the subtropics and tropics of Queensland, Australia. V2.
Sud99 Nasserulla, S.M. et al. (1999) Vegetation status of the revegetated acid generating tailings at Elliot Lake, Ontario, Canada. V2.
Sud99 Sotir, R.B. et al., (1999) Soil bioengineering methods for abandoned mine land surface drainage channels. V2.
Sud99 Tae, M. (1999) Species selection for vegetating and engineered pit cover in the Sudbury area. V2.
Sud99 Winterhalder, K. (1999) The feasibility and implications for biodiversity ecosystem function and metal cycling of employing reciprocal transplants between metal contaminated mine sites as part of a revegetation study. V2.

a. Bactericides

611. Kleinmann,Robert LP (1982): Full-Scale Field Trials of a Bactericidal Treatment to Control Acid Mine Drainage. In: 1982 Symposium on Surface Mining Hydrology. (Ed: University of Kentucky) University of Kentucky, Lexington, Kentucky, 617-622.
772. Rastogi,Vijay; Sobek,Andrew A (1986): The economics of using bactericides in active,mining and in reclamation to control acid mine drainage. In: 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation. (Ed: Unknown) University of Kentucky, Unknown, 215. (Symposium held at University of Kentucky, Lexington, Kentucky on Dec. 8-11)
1254. Kleinmann,Robert LP; Erickson,Patricia M (1800): Control of acid drainage from coal refuse using anionic surfactants. (Report of Investigations 8847) U.S. Department of the Interior, Bureau of Mines, Pittsburgh, PA.
1255. Rastogi,V; Sobek,AA; Benedetti,DA (1990): Prevention of water pollution problems in mining: The bactericide technology. (Presented at GOLDTech 4, Reno, NV, September 10-12; Preprint Number 90-409) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO.
1256. Benedetti,Donald A; Rastogi,Vijay; Sobek,Andrew A (1990): Minimizing water treatment costs at active operations. Presented at National Symposium on Mining, Knoxville, TN, May 14-19.
1257. Sobek,Andrew A; Benedetti,Donald A; Rastogi,Vijay (1990): Successful reclamation using controlled release bactericides: Two case studies. Presented at American Society for Surface Mining and Reclamation Conference, April 23-26, Charleston, WV.
1526. Sobek,Andrew A (1987): The use of surfactants to prevent AMD in coal refuse and base metal tailings. In: Proc. acid mine drainage seminar/workshop. (Seminar held in Halifax, Nova Scotia, March 23-26) (Ed: Environment Canada) Environment Canada, Ottawa, 357-390.
2588. Anonymous (1996): Bactericide treatment helps save at coal reclamation site. Mining Engineering 48(September), 16.
3481. Benedetti,Donald A (1990): ProMac systems and artificial wetlands. ProMac Progress IV(2, July), 1.
3514. Kleinmann,Robert LP (1980): Bacterial control of acid problems in surface mine and coal refuse. In: Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation. (December 1-5, 1980) (:) University of Kentucky,, 333-337.
3515. Rastogi,Vijay (1995): ProMac: Bacterial inhibition. Mining Environmental Management 3, 27-29.
Pitt94 Parisi, D. et al. (1994) Use of bactericides to control acid mine drainage from surface operations. V2.
Sud95 Stichbury, M. et al. (1995) Use of inhibitors to prevent acid mine drainage
Van97 Delaney, T. et al. (1997) Applications of methods for delaying the onset of acidic drainage. V2.
Sud99 Lortie, L. et al. (1999) Inhibitors for the prevention of acid mine drainage (AMD). V3.
Ziemkiewicz, P.F. (1995) Acid mine drainage control technologies. Ch 5. Acid Mine Drainage Control and Treatment.

b. Compost & Biosolids

3230. Silver,M; Ritcey,GM (1985): Effects of iron-oxidizing bacteria and vegetation on acid generation in laboratory lysimter tests on pyrite-containing uranium tailings. Hydrometallurgy 15, 255-264.

c. Fungi

d. Soil Amendments

1181. Hinkle,Kenneth R (1984): Project Summary: Reclamation of Toxic Mine Waste Utilizing Sewage Sludge: Contrary Creek Demonstration Project, Addendum Report. (S2-84-016) U.S. Envrionmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, OH. 4 pages.

1182. Hinkle,Kenneth (1982): Project Summary: Reclamation of Toxic Mine Waste Utilizing Sewage Sludge-Contrary Creek Demonstration. U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Cincinnati, OH. 4 pages.

1183. Sopper,William E; Seaker,Eileen M (1984): Project Summary: Strip Mine Reclamation with Municipal Sludge. U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, OH.

e. Specialized Vegetation

2504. Morrey,David R (1995): Using metal-tolerant plants to reclaim mining wastes. Mining Engineering 47(March), 247-249.

Tmw99 Williams, B.C. et al. (1999) Demonstration of metals-fixation technologies on the Coeur d'Alene River, Idaho. pg 707.

A1.5. Selective Handling

1400. Robinskyl,E; Barbour,SL; Wilson,GW; Bordin,D; Fredlund,DG (1991): Thickened sloped tailings disposal - An evaluation of seepage and abatemnet of acid drainage. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 529-549.

1784. Wilkerson,Daniel L; Fristoe,Bradley (1800): Managing drilling wastes in a northern environment. In: Proc. Symposium on Water Resources Related to Mining and Energy - Preparing for the Future. (Ed: Dworsky,Richard F) American Water Resources Association, Bethesda, Maryland, 501-508.

3033. Anonymous (1995): Revolutionary device may blow AMD away. West Virginia Coal Bell, .

3270. Environmental Protection Agency (1993): Cyanide heap leach and tailings impoundments closure. US Envivironmental Protection Agency, Crystal City, VA.

3405. Domvile,Serena; Li,Michael; Sollner,Diana; Nesbitt,Wayne (1800): Investigation of weathering behavior of mine tailings under laboratory-simulated disposal conditions., . 21 pages.

3640. Flather,DH; Drover,K; Hendry,JW (2000): Development of a simple segregation program to manage potentially acid generating waste rock at the Keystone Gold Mine, Manitoba. CIM Bulletin 93(1037), 58-60.

3679. Ulrich,B; East,DR; Gorman,J (2000): Subaerial tailing deposition -- design, construction, and operation for facility closure and reclamation. In: Tailings and Mine Waste 2000. (:) AA Balkema, Rotterdam, Netherlands,

a. Backfilling

1174. Walker,Jeffrey S (1993): State-of-the-art Techniques for Backfilling Abandoned Mine Voids. (Information Circular 9359) United States Department of the Interior, Bureau of Mines, Pittsburgh, PA. 17 pages.

1178. Pionke,HB; Rogowski,AS (1979): How effective is the deep placement of acid spoil materials? Presented at Canadian Land Reclamation Association's 4th Conference, Saskatchewan, July 13-15, 1979.

2676. Levens,RL; Boldt,CKM (1992): Hydrochemical impacts of mine waste backfill in underground sulfide mines. In: Environmental issues and waste management in energy and minerals production. (Ed: Singhal) Balekema, Rotterdam, 891-902.

Pitt94 Cravotta, C.A. III et al. (1994) Geochemical and geohydrological characteristics of bedrock and spoil from two methods of mining at a reclaimed surface coal mine, Clarion County, PA, USA. V2.

Sud95 Burnett, J.M. et al. (1995) pneumatic backfilling of coal combustion residues in underground mines.

Sud95 Hu, Z. (1995) Coal waste disposal and management in Chinese Shuoli mine.

Sud95 Michaud, L.H.; Bjork, D. (1995) The feasibility of constructing solid waste landfills as a reclamation method for abandoned mine lands.

Tmw97 Dahlstrom, D.A. (1997) Disposal of fine tailings in the underground mine.

Tmw97 Dusseault, M.B.; Davidson, B.C. (1997) Salt solution cavern disposal for toxic solid mining wastes.

Van97 Helms, W.; Heinrich, D. (1997) Development of backfill material for minimizing acid mine drainage generation in abandoned underground mines. V3.

Van97 Hockley, D. et al. (1997) Relocation of waste rock to the Lichtenberg Pit near Ronneburg, Germany. V3.

Van97 Lewis-Russ, A. et al. (1997) Control of acid rock drainage by pit backfilling. V3.

Tmw98 Chapman, J. et al. (1998) Pit backfilling on two continents: Comparison of recent experiences.

Tmw98 Sevick, G.W. et al. (1998) Engineered open pit mine backfilling.

Tmw99 Hill, T.H.; Benson, C.H. (1999) Hydraulic conductivity of compacted mine rock backfill.

Tmw99 Qiu, Y.; Sego, D.C.; Szymanski, J. (1999) Innovative tailings backfill using HSM.

Tmw99 Scheetz, B.E.; Schantz, C.R. (1999) Utilization of dredge material-based grouts for mineland reclamation. pg 749.

Sud99 Kerr, T. et al. (1999) Use of a by-product to mitigate acid mine drainage from an historic mine at Goudreau, Ontario. V3.

Sud99 Ketallapper, V.L.; Christiansen, J.W. (1999) Effectiveness of site stabilization activites at the Summitville mine to reduce acid rock drainage. V1.

High density slurry

Pitt94 Murdock, D.J. et al. (1994) Treatment of acid mine drainage by the high density sludge process. V1.

Pitt94 Tom, A.A. et al. (1994) The pore-water geochemistry of the Cu-Zn mine tailings at Kidd Creek, near Timmins, Ontario, Canada. V2.

Pitt94 Woyshner, M.R.; St-Arnaud, L. (1994) Hydrogeological evaluation and water balance of a thickened tailings deposit near Timmins, ON, Canada. V2.

Van97 Aube, B.; Payant, S. (1997) The Geco Process: A now high density sludge treatment for acid mine drainage. V1.

Tmw99 Williams, M.P.A.; Seddon, K.D. (1999) Thickened tailings discharge: A review of Australian experience. pg 125.

Paste technology

Tmw98 Gay, F.; Constantiner, D. (1998) Additives for improving paste backfill mixes.

Tmw98 Ouellet, J. et al. (1998) Mechanical, Mineralogical and chemical characterization of a paste backfill.

Tmw99 Chen, L.J.; Millette, D.G.; Annor, A. (1999) A new development in paste backfill technology.

Sud99 Bernier, L.R. et al. (1999) Effects of tailings and binder geochemistry on the physical strength of paste backfill. V3.

Selective placement

609 Infanger, M.; Hood, W.C. (1980) Positioning acid-prodcing overburden for minimal pollution. In: Symp. On Surface Mining Hydrology, Sedimentology and Reclamation. Pg 325.

1178 Pionke, H.B.; Rogowski, A.S. (1979) How effective is the deep placement of acid spoil materials?

1585 Wathne, M. (1988) Water quality improvement by stream regulation.

1612 Strachan, C.L.; Shephard, T.A. (1990) Design issues associated with reclamation of uranium tailings impoundments.

1622 Kelsh, D.J. (1990) Tailings pond dewatering and consolidation by electroosmosis/electrophoresis.

1623 East, D.R. (1990) Performancde achievements of drained managed tailings storage facilities.

1624 Miller, L.L et al. (1990) The impact of consolidation on the reclamation of tailings impoundments.

1666 Fossberg, E.; Andreasson, B. (1992) Stabilization of mineral processing wastes.

2885 Michaud, L.H. (1995) Selective spoil placement for the prevention of acid mine drainage formation.Pitt94 Ziemkiewicz, P.F.; Meek, F.A. Jr. (1994) Long term behavior of acid forming rock: Results of 11-year field studies. V2.

Van97 Schafer, W.M. et al. (1997) Control of tailings oxidation rate using spigotting techniques. V3.

Tmw98 Austiguy, G.E. et al. (1998) Lower Area One- Phase 1: Remediation of a metals tailings contaminated site.

b. In-situ Leach Mining

Sud99 Geisler, R.A. (1999) In situ leach mining the Yava lead deposit offers a new paradigm to prevent acid rock drainage and achieve sustainable mineral resource development. V3.

c. Remining/Removal of Toxic Materials

1401. Britton,RR; Gozon,JS; Beach,KD (1991): Acid mine drainage control by re-mining. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 551-559.

1732. Fleming,SP; Cho,EG (1992): Leaching of nickel and cobalt from acid mine drainage sludge. (Presented at 1992 SME Annual Meeting, Phoenix, AZ, Feb. 24-27; Preprint Number 92138) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO.

1741. Trezek,GJ (1992): Remediation of heavy metals in soils and sludges. (Presented at 1992 SME Annual Meeting, Phoenix, AZ, Feb. 24-27; Preprint Number 9295) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO.

2436 Hawkins, J.W. (1994) A statistical evaluation of remining abandoned coal mines to reduce the effluent contaminant load.

Desulfurization of tailings

Sud95 Humber, A.J. (1995) Separation of sulfide minerals from mill tailings.

Sud99 Benzaazoua, M.; Bussiere, B. (1999) Desulphurization of tailings with low neutralizing potential: kinetic study and flotation modeling. V1.

A1.6. Source Control of AMD

291. Shumate,Kenesaw S; Smith,EE; Ricca,Vincent T; Clark,Gordon M (1976): Resources Allocation to Optimize Mining Pollution Control. (Contract No. 68-10-0724: EPA-600/2-76-112) Industrial Environmental Research Laboratory, Office of Research and Development and U.S. Environmental Protection Agency, Cincinnati, OH.

660. Craze,B (1990): Mine waste pollution control at Captains Flat, New South Wales. In: Biogeochemistry of Ancient and Modern Environments. (Eds: Trudinger,Walter; Trudinger,Ralph) Austrailia Academy of Science, Canberra, Austrailia, 705-7123.

684. Jennett,J Charles; Bolter,E; Gale,N; Tranter,W; Hardie,M (1800): The Viburnum Trend, southeast Missouri: The largest lead-mining district in the world - environmental effects and controls. Unknown, 13-26.

915. Range,DM (1989): Exxon reclaims its Highland uranium tailings basin in Wyoming. Mining Engineering (August), 831-834.

936. Williams,Roy E (1988): Evaluation of waste and water contamination for closure of a hard rock mine complex. U.S. Bureau of Mines, Unknown. (Quarterly Report to the US Bureau of Mines (Sept. and Oct.))

937. Riley,John A (1985): Acid water implications for mine abandonment, Coeur D'Alene mining district, Idaho. (Report submitted to Mineral Industry Waste Treatment and Recovery Generic Center) University of Idaho, Moscow, Idaho. 148 pages.

940. Sonderegger,John L; Wallace,Jospeh J Jr; Higgins,Grove L Jr (1975): Acid mine drainage control-feasibility study, Cooke City, Montana. (Report submitted to the Department of Natural Resources and Conservation; Grant No. S-802671) Montana Bureau of Mines and Geology, Unknown.

941. Hill,Ronald D; Montana Department of Natural Resources and Conservation-Engineering Bureau (1977): Mine drainage control from metal mines in a subalpine environment: A feasibility study. Industrial Environmental Research Laboratory, Office of REsearch and Development, Cincinnati, OH.

970. Watkin,EM; Watkin,J (1983): Inhibiting pyrite oxidation can lower reclamation costs. Canadian Mining Journal 104(12, December), 29-31.

1114. Horowitz,Arthur J; Elrick,Kent A; Cook,Robert B (1992): Effect of Mining-Related Activities on the Sediment-Trace Element Geochemistry of Lake Coeur d'Alene, Idaho, USA--Part 1: Surface Sediments. (Open File Report 92-109) U.S. Geological Survey, Doraville, GA.

1497. Lundgren,Tom A (1990): Cleaning up River Dalalven, Sweden - An attempt to counteract the main part of acid mine drainage sources in Sweden. In: Acid mine drainage: Designing for closure. (Presented at GAC/MAC Joint Annual Meeting in Vancouver, May 16-18) (Eds: Gadsby,John W; Malick,James A; Day,Stephen J) BiTech Publishers Ltd., Vancouver, BC, 203-215. (N)

1535. Ferguson,K; Robertson,AM; Robertson,Steffen (1987): The control and treatment of AMD from an

abandoned open pit and waste rock dump. In: Proc. acid mine drainage seminar/workshop. (Seminar held in Halifax, Nova Scotia, March 23-26) (Ed: Environment Canada) Environment Canada, Ottawa, 597-605.

1649. Colbert,Thomas A (1991): Reclamation of acid-forming tailing in the western US - Good news at last. Chap. 29. In: Environmental Management for the 1990's. (Proc. Symposium on Environmental Management for the 1990's, Denver, CO, February 25-28) (Eds: Lootens,Douglas J; Greenslade,William M; Barker,James M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 213-216.

1791. Hawley,John R (1977): Mine waste control in Ontario. Ontario Ministry of the Environment, Ontario. 224 pages.

2524. Cadwaller,Mark W (1800): Cost effective tailings pond and heap leach pad liners: A case history. Chap. 23. In: Small Mines Development in Precious Metals. (Ed: Unknown) Unknown,, 145-150.

2525. Kurtz,Jeffrey P (1800): Clay problems encountered in gold heap leaching. Chap. 26. In: Small Mines Development in Precious Metals. (Ed: Unknown) Unknown,, 161-167.

2561. Anonymous (1996): Containment of Mining Wastes and Reuses and the Third International Symposium on Environmental Geotechnology, San Diego, California. June 10-12, 1996.

a. Bulkheads

b. Grouting Mine Workings

2950. McIntyre,T; McCloskey,A (1994): Grouting as a Hydrological Control for Acid Rock Drainage Reduction at the Mike Horse Mine near Lincoln, Montana. In: Mine Design, Operations & Closure Conference: Mining and the Environment. (Mine Waste Technology Pilot Program: Activity III, Project 2,Contract No. DE-AC22-881D12735) (Ed: Unknown) MSE, Inc., Butte, Montana, 1-37.

Pitt94 Klimkos, M.J. (1994) Nine yards and a cloud of dust (The operation of a fly ash grouting process to abate an acid mine drainage discharge). V2.

Pitt94 Schueck, J. et al. (1994) Acid mine drainage abatement using fluidized bed combustion ash grout after geophysical site characterization. V4.

Tmw97 Fuenkajorn, K.; Daemen, J.J.K. (1997) Mine sealing: Design guidelines and considerations.

Tmw98 Scheetz, B. et al. (1998) Acid mine drainage abatement resulting from pressure grouting of buried bituminous mine spoils.

c. Organic Matter/Biomass Reactors

d. Phosphate Armoring

e. Solidification/Stabilization

1666. Forssberg,Eric; Andreasson,Benny (1992): Stabilization of mineral processing wastes. Chap. 30. In: Emerging process technologies for a cleaner environment. (Proc. Symposium on Emerging Process Technologies for a Cleaner Environment, February 24-27, Phoenix, Arizona) (Eds: Chander,S; Richardson,PE; El-Shall,H) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 223-230.

A1.7. Active Treatment Systems

56. Meyer,Klaus (1992): The David Bell Mine water quality management strategy. CIM Bulletin 85(963), 27-30.

563. U.S. Army Engineer Waterways Experiment Station,Vicksburg,MS (1984): Evaluation of the RCRA Extraction Procedure: Lysimeter Studies with Municipal/Industrial Wastes. (EPA-600/S2 84-022) (Project Summary.) US Government Printing Office, Cincinnati, Ohio. 3 pages.

799. Skousen,Jeff; Politan,Ken; Hilton,Tiff; Meek,Al (1990): Acid mine drainage treatment systems: Chemicals and costs. Green Lands Unknown, 31-37.

800. Kordosky,GA; Champion,WH; Dolegowski,JR; Olafson,SM; Jensen,WS (1981): Use of pH control in solvent extraction circuits. Mining Engineering, 291-299.

806. Jeffers,TH; Groves,RD (1985): Using solvent-impregnated carbon to recover copper from oxidized mill tailings. (Report of Investigations 8966) United Staes Deartment of the Interior, Bureau of Mines, Pittsburgh, PA.

938. Manitoba Environmental Management Division (1981): Hudson Bay Mining & Smelting Co. Ltd.,

Flin Flon Mining Complex. Environmental Report.
1134. Reddy,RG; Hendrix,JL; Queneau,PB (Eds.) (1988): Proc. 1988 TMS Annual Meeting and Exhibition: Arsenic Metallurgy--Fundamentals and Applications Symposium. (Symposium held in Phoenix, AZ, January 25-29) The Metallurgical Society, Inc., Warrendale, PA.
1235. Boyles,J Michael; Cain,Doug; Alley,William; Klusman,Ronald W (1974): Impact of Argo tunnel acid mine drainage, Clear Creek County, Colorado. Water Resources Problems Related to Mining Unknown, 41-53. (Proc. No. 18)
1265. Navratii,James D (1990): Metal recovery and waste processing using ferrites. In: EPD Congress 1990. (Ed: Gaskell,DR) The Minerals, Metals, and Materials Society, Unknown, 125-128. (Presented at EPD Congress, Anaheim, CA, Feb 19-22)
1281. Theis,Thomas L; Young,Thomas C; Huang,Mohul; Knutsen,Kenneth C (1994): Leachate characteristics and composition of cyanide-bearing wastes from manufactured gas plants. Environ. Sci. Technol. 28(1, January), 99-106.
1331. Karam,Antoine (1991): Effet de l'utilisation de boues sur la qualite des effluents miniers acides. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 3. (Ed: MEND Program) Quebec Mining Association, Ottawa, 577-586.
1337. Kondos,PD; MacDonald,RJC; Zinck,JM (1991): Studies on the removal of heavy metals from acidic mineral effluents. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. (Ed: MEND Program) Quebec Mining Association, Ottawa, 47-70.
1357. Gussmann,HW; Everett,DJ; Du Plessis,J (1991): The treatment of underground mine waters for the removal of calcium and sulphates by a GYP-CIX process. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. (Ed: MEND Program) Quebec Mining Association, Ottawa, 377-390.
1402. Fletcher,JJ; Phipps,TT; Skousen,JG (1991): Cost analysis for treating acid mine drainage. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 561-574.
1418. Bureau of Mines (Ed.) (1988): Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. 2 vols. (Proc. of conference sponsored by The American Society for Surface Mining and Reclamation, The Bureau of Mines, and The Office of Surface Mining Reclamation and Enforcement, Pittsburgh, PA, April 19-21; Information Circular 9183) U.S. Department of the Interior, Pittsburgh. 413 pages.
1500. Ryan,Peter; Joyce,Chris (1990): Integrated environmental engineering for acid mine drainage control in Australia. In: Acid mine drainage: Designing for closure. (Presented at GAC/MAC Joint Annual Meeting in Vancouver, May 16-18) (Eds: Gadsby,John W; Malick,James A; Day,Stephen J) BiTech Publishers Ltd., Vancouver, BC, 255-272. (N)
1515. Burbank,Arthur L; Oliver,Daivd J; Prisbrey,Keith A (1990): Bacterial sulfur cycling in acid mine drainage. In: Acid mine drainage: Designing for closure. (Presented at GAC/MAC Joint Annual Meeting in Vancouver, May 16-18) (Eds: Gadsby,John W; Malick,James A; Day,Stephen J) BiTech Publishers Ltd., Vancouver, BC, 463-470. (N)
1530. Caruccio,Frank T; Geidel,Gwendelyn (1987): The in-situ mitigation of acidic drainages - Management of hydro-geochemcial factors. In: Proc. acid mine drainage seminar/workshop. (Seminar held in Halifax, Nova Scotia, March 23-26) (Ed: Environment Canada) Environment Canada, Ottawa, 479-497.
1562. Chilton,Dan R (1992): Watershed reclamation at Butler Taconite, under Minnesota DNR "Rules related to mineland reclamation" Chapter 6130--6130.01-6130.63. In: Achieving land use potential through reclamation. (ASSMR9-92) (Ed: American Society for Surface Mining and Reclamation) American Society for Surface Mining and Reclamation, WV, 705-722.
1582. Ericson,Patricia (1988): Chemical and biological methods to mitigate acid mine drainage. Chap. 20. In: Proc. International Conference on Control of Environmental Problems from Metal Mines. (Eds: State Pollution Control Authority; Federation of Norwegian Industries) State Pollution Control Authority, Norway, none.
1584. Pietersen,Hans S; van Herk,Joost; Schuiling,Roelof D (1988): The olivine process - Waste acid

neutralization by reaction with a magnesium silicate. Chap. 22. In: Proc. International Conference on Control of Environmental Problems from Metal Mines. (Eds: State Pollution Control Authority; Federation of Norwegian Industries) State Pollution Control Authority, Norway, 11pages.

1662. Malhotra,Deepak; Tuka,Richard F (1992): Overview of water treatment technologies. Chap. 22. In: Emerging process technologies for a cleaner environment. (Proc. Symposium on Emerging Process Technologies for a Cleaner Environment, February 24-27, Phoenix, Arizona) (Eds: Chander,S; Richardson,PE; El-Shall,H) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 169-173.

1674. Mining Association of British Columbia; Ministry of Energy,Mines and Petroleum Resources; Ministry of Environment (1989): Water Management at Minesites. (Proc. 13th Annual British Columbia Mine Reclamation Symposium) Ministry of Energy, Mines and Petroleum Resources, Victoria, BC. 221 pages.

1675. Brown,Ronald (1989): Water management at Brenda Mines. Chap. 1. In: Water Management at Minesites. (Proc. 13th Annual British Columbia Mine Reclamation Symposium) (Eds: Mining Association of British Columbia; Ministry of Energy,Mines and Petroleum Resources; Ministry of Environment) Ministry of Energy,Mines and Petroleum Resources, Victoria, BC, 7-17.

1738. Mehta,RK; Zhang,L; Warren,GW (1992): Chemoremediation of acid mine drainage by controlled ferrite coprecipitation and magnetic separation. (Presented at 1992 SME Annual Meeting, Phoenix, AZ, Feb. 24-27; Preprint Number 92216) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO.

1799. Scott,JS; Bragg,K (Eds.) (1975): Mine and mill wastewater treatment. (Economic and Technical Review Report No. EPS 3-WP-75-5) Environmental Protection Service, Ontario. 141 pages.

1909. Permutit (1977): SULFEX: Heavy metals waste treatment process. Permutit: Technical Bulletin 13, 6.

1911. Larsen,H Peter; Ross,Laurence W (1976): Two-stage process chemically treats mine drainage to remove dissolved metals. E&MJ February, 94-96.

1929. Oko,JM; Taylor,LW (1974): Treatment of acid mine wastewater at Falconbridge's Hardy Crown Pillar Project. The Canadian Mining and Metallurgical (CIM) Bulletin 67(744), 43-49.

1934. Iwasaki,I; Malicsi,AS; Smith,KA; Christensen,BL (1976): A preliminary study of release and removal of copper and nickel ions in mine and mill effluents. In: Proc. 49th Annual Meeting, Minnesota Section, AIME and 37th Annual Mining Symposium. (January 14-16, 1976) (Ed: Unknown) Unknown, Unknown, 26-1 - 26-31.

2175. Orr,RG; Aldag,WJ; Laine,OA; Anderson,WT (1992): Recovery of nickel from waste materials. In: Waste Processing and Recycling in Mining and Metallurgical Industries. (Eds: Rao,SR; Amaratunga,LM; Boateng,DAD; Chalkley,ME) Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 23-33.

2259. Anonymous (1990): EPA planning to treat, but not pump, water in Berkeley Pit. Rocky Mountain PAY DIRT Unknown, 13A. (Excerpted from the Montana Standard (April 13, 1990))

2599. Skousen,Jeff; Hilton,Tiff; Faulkner,Ben (1996): Overview of acid mine drainage treatment with chemicals. Green Lands 26(4), 36-45.

3132. Ziemkiewicz,Paul; Skousen,Jeff (1998): The use of steel slag in acid mine drainage treatment and control. Green Lands 28, 46-56.

3229. Schackelford,JM (1973): Water reuse in industry Part 3 -- Mine Water. Mechanical Engineering 95(6), 32-34.

3326. Iwasaki,I; Smith,KA (1975): Removal of potential copper and nickel pollutants from mine and mill effluents -- a preliminary study. Presented at Duluth Mining Symposium.

3653. Saha,S (1993): Treatment of aqueous effluent for fluoride removal. Water Research 27(8), 1347-1350.

Pitt94 Hubbard, K.L. et al. (1994) New functional polymers as sorbents for the selective recovery of toxic heavy metals from acid mine drainage. V2.

Tmw97 Wang, G. et al. (1997) Effluent treatment for removal of cyanide and nitrogen compounds.

Van97 Miedecke, J. et al. (1997) Remediation options (including copper recovery by SX/EW) to reduce acid drainage from historical mining operations at Mount Lyell, Western Tasmania, Australia. V4.

Sud99 Aube, B.C.; Zinck, J.M. (1999) Comparison of AMD treatment processes and their impact of sludge

characteristics. V1.

Sud99 Hallett, C.J. et al. (1999) Wheal Jane-The appraisal and selection of the long-term option for minewater treatment. V2.

a. Aeration/oxidation

1432. Jageman,TC; Yokley,RA; Heunisch,GW (1988): The use of pre-aeration to reduce the cost of neutralizing acid mine drainage. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 131-135.

1476. Ackman,TE; Hustwit,CC (1988): Aeration efficiency of the in-line aeration and neutralization system. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 403.

1907. Ackman,Terry; Kleinmann,Robert LP (1985): In-line aeration and treatment of acid mine drainage: Performance and preliminary design criteria. U.S. Bureau of Mines, Pittsburgh, PA. 61 pages.

3344. Mihok,EA (1800): Applied advance technology to eliminate aeration in mine water treatment. In: Unknown. (:),, 181-187.

b. Biological

808. Jeffers,Thomas H (1991): Using microorganisms to recover metals. Minerals Today (June), 14-18.

809. Unknown (1800): An outline of the bio separation process. Bio Separation Ltd, England.

815. Michaelis,Hans Von (1986): Integrated biological systems for effluent treatment from mine and mill tailings. Chap. 7. In: Fundamental and Applied Biohydrometallurgy. (Proc. 6th International Symposium on Biohydrometallurgy in Vancouver, BC, Canada, August 21-24, 1985) (Eds: Lawrence,Richard W; Branion,Richard MR; Ebner,Hans G) Elsevier, Amsterdam, 311-326.

816. Whitlock,James L; Mudder,Terry I (1986): The homestake wastewater treatment process: Biological removal of toxic parameters from cyanidation wastewaters and bioassay effluent evaluation. Chap. 7. In: Fundamental and Applied Biohydrometallurgy. (Proc. 6th International Symposium on Biohydrometallurgy in Vancouver, BC, Canada, August 21-24, 1985) (Eds: Lawrence,Richard W; Branion,Richard MR; Ebner,Hans G) Elsevier, Amsterdam, 327-339.

826. Kalin,M (1986): Ecological engineering: Evidence of a viable concept. Chap. 10. In: Fundamental and Applied Biohydrometallurgy. (Proc. 6th International Symposium on Biohydrometallurgy in Vancouver, BC, Canada, August 21-24, 1985) (Eds: Lawrence,Richard W; Branion,Richard MR; Ebner,Hans G) Elsevier, Amsterdam, 489-490.

827. Kalin,M; Smith,MP (1986): Biological polishing agents for mill waste water, an example: chara. Chap. 10. In: Fundamental and Applied Biohydrometallurgy. (Proc. 6th International Symposium on Biohydrometallurgy in Vancouver, BC, Canada, August 21-24, 1985) (Eds: Lawrence,Richard W; Branion,Richard MR; Ebner,Hans G) Elsevier, Amsterdam, 491-492.

828. Carta,M; Ghiani,M; Rossi,G (1980): Biochemical beneficiation of mining industry effluents. In: Biogeochemistry of Ancient and Modern Environments. (Proc. 4th International Symposium on Environmental Biogeochemistry (ISEB) and Conference on Biogeochemistry in Relation to the Mining Industry and Environmental Pollution (Leaching Conference) held in Canberra, Australia, 26 August-4 September 1979) (Eds: Trudinger,PA; Walter,MR; Ralph,BJ) Springer-Verlag, Berlin-Heidelberg-New York, 669-688.

927. Larsen,DM; Gardner,KR; Altringer,PB (1987): A biohydrometallurgical approach to selenium removal. In: Water Resources Related to Mining and Energy-Preparing for the Future. (Ed: Dworsky,RF) American Water Resources Association, Bethesda, Maryland, 419-426.

1138. Brierley,JA; Brierley,CL; Goyak,GM (1986): AMT-BIOCLAIM: A new wastewater treatment and metal recovery technology. In: Fundamental and Applied Biohydrometallurgy. (Proc. 6th International Symposium on Biohydrometallurgy, Vancouver, BC, Canada, August 21-24, 1985) (Eds: Lawrence,Richard W; Branion,Richard,MR; Ebner,Hans G) Elsevier, Amsterdam, 291-304.

1142. Townsley,CC; Ross,IS; Atkins,AS (1986): Biorecovery of metallic residues from various industrial effluents using filamentous fungi. In: Fundamental and Applied Biohydrometallurgy. (Proc. 6th International Symposium on Biohydrometallurgy in Vancouver, BC, Canada, August 21-24, 1985) (Eds: Lawrence,Richard W; Branion,Richard MR; Ebner,Hans G) Elsevier, Amsterdam, 279-289.

1143. Livesey-Goldblatt,Eric (1986): Bacterial leaching of gold, uranium, pyrite bearing compacted mine

tailing slimes. In: Fundamental and Applied Biohydrometallurgy. (Proc. 6th International Symposium on Biohydrometallurgy in Vancouver, BC, Canada, August 21-24, 1985) (Eds: Lawrence,Richard W; Branion,Richard MR; Ebner,Hans G) Elsevier, Amsterdam, 89-96.

1284. Kleinmann,RLP; Hedin,RS; Edenborn,HM (1991): Biological treatment of mine water--An overview. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 4. (Ed: MEND Program) Quebec Mining Association, Ottawa, 27-42.

1309. Bechard,G; Goudey,P; Rajan,S; McCready,RGL (1991): Microbiological process for the treatment of acidic drainage at the Halifax International Airport. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 3. (Ed: MEND Program) Quebec Mining Association, Ottawa, 171-183.

1386. Bennett,PG; Ferguson,CR; Jeffers,TH (1991): Biolgocial treatment of acid mine waters - case studies. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 283-299.

1387. Dvorak,DH; Hedin,RS; Edenborn,HM; Gustafson,SL (1991): Treatment of metal-contaminated water using bacterial sulfate reduction: Results from pilot-scale reactors. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 301-314.

1388. Barrette,LM; Couillard,D (1991): Lixiviation bacterienne d'un terril de gisement sulfureux a l'aide d'un bioreacteur a ascension pneumatique. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 315-333.

1389. Kuyucak,N; Lyew,D; St-Germain,P; Wheeland,KG (1991): In situ bacterial treatment of AMD in open pits. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 335-353.

1390. Kalin,M; Smith,MP (1991): Biological amelioration of acidic seepage streams. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 355-368.

1391. Blenkinsopp,SA; Herman,DC; Costerton,JW (1991): The use of biofilm bacteria to exclude oxygen form acidogenic mine tailings. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 369-377.

1448 Nakamura, K. (1988) Biological metal removal from mine drainage.

1488 Mann, H. et al. (1990) Metal accumulation and Fe, Ti-oxide biomineralization by acidophilic microorganisms in mine waste environments.

1585. Wathne,Mange (1988): Water quality improvement by stream regulation. Chap. 23. In: Proc. International Conference on Control of Environmental Problems from Metal Mines. (Eds: State Pollution Control Authority; Federation of Norwegian Industries) State Pollution Control Authority, Norway, 12pages.

1587. Hallberg,Rolf O (1988): Enhanced bacterial leaching and sulfide precipitation to prevent metal pollution from sulfide ore tailings and dumps. Chap. 25. In: Proc. International Conference on Control of Environmental Problems from Metal Mines. (Eds: State Pollution Control Authority; Federation of Norwegian Industries) State Pollution Control Authority, Norway, 4pages.

1629. Thompson,LC; Gerteis,RL (1990): New technologies for mining waste management biotreatment processes for cyanide, nitrates and heavy metals. Chap. 34. In: Mining and mineral processing wastes. (Proc. Western Regional Symposium on Mining and Mineral Processing Wastes, Berkeley, CA, May 30-June 1) (Ed: Doyle,Fiona M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 271-278.

1630. Bennett,PG; Jeffers,TH (1990): Removal of metal contaminants from a waste stream using bio-fix beads containing sphagnum moss. Chap. 35. In: Mining and mineral processing wastes. (Proc. Western Regional Symposium on Mining and Mineral Processing Wastes, Berkeley, CA, May 30-June 1) (Ed: Doyle,Fiona M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 279-286.

1640. Lien,RH; Dinsdale,BE; Altringer,PB (1991): Biological and chemical cyanide destruction from heap leachates and residues. Chap. 18. In: Environmental management for the 1990's. (Proc. Symposium on Environmental Management for the 1990's, Denver, CO, February 25-28) (Eds: Lootens,Douglas J;

Greenslade,William M; Barker,James M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 123-133.

1643. Rech,William; Jones,Jay (1991): Case history of mine water treatment at the Henderson Mine and the adaptation to bio-monitoring regulations. Chap. 21. In: Environmental Management for the 1990's. (Proc. Symposium on Environmental Management for the 1990's, Denver, CO, February 25-28) (Eds: Lootens,Douglas J; Greenslade,William M; Barker,James M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 151-155.

1665. Thompson,LC (1992): Developments in mine waste biotreatment processes. Chap. 26. In: Emerging process technologies for a cleaner environment. (Proc. Symposium on Emerging Process Technologies for a Cleaner Environment, February 24-27, Phoenix, Arizona) (Eds: Chander,S; Richardson,PE; El-Shall,H) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 197-204.

1875. Reddy,KR; Smith,WH (Eds.) (1987): Aquatic plants for water treatment and resource recovery. Magnolia Publishing Inc., Orlando, FL. 1024 pages.

1923. Khalafalla,SE; Engelmann,WH (1980): Bacterial inhibition of acid pollution in mine drainage. In: Bureau of Mines Research. (Ed: Burket,Janice D) U.S. Bureau of Mines, Unknown, 35-36.

1912 Pugsley, E.B. et al. (1971) Removal of heavy metals from mine drainage in Colorado by precipitaiton.

2179. Tackaberry,PD; Lakshmanan,VI; Heinrich,GW; Collins,M; McCready,RGL (1992): Biohydrometallurgical leaching of nickel values from Falconbridge pyrrhotite tailings. In: Waste Processing and Recycling in Mining and Metallurgical Industries. (Eds: Rao,SR; Amaratunga,LM; Boateng,DAD; Chalkley,ME) Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 193-211.

2260. Bio Separation Ltd (1800): An outline of the bio separation process. Bio Separation Ltd, England. 7 pages.

2292 Hancock, I.C. (1986) The use of gram-positive bacteria for the removal of metals from aqueous solution.

2331. Muraleedharan,TR; Iyengar,Leela; Venkobachar,C (1991): Biosorption: An attractive alternative for metal removal and recovery. Cuurent Science 61(6, 25 September), 379-385.

2337. Hutchison,SR; Davidson,MS; Brierley,JA; Brierley,CL (1986): Microorganisms in reclamation of metals. Ann. Rev. Microbiol. 40, 311-336.

2470. Rusin,P; Cassells,J; Quintana,L; Arnold,R; Chrisman,N (1995): Elimination of toxic factors in leachate to enhance biooxidation of sulfide ores. Mining Engineering 47(2), 173-177.

2571. Eger,Paul (1992): The use of sulfate reduction to remove metals from acid mine drainage. In: Proceedings for the American Society for Surface Mining and Reclamation Meeting. (:) ASSMR,, 563-575.

2656. Salt,David E; Pickering,Ingrid J; Prince,Roger C; Gleba,Deloressa; Dushenkov,Slavik; Smith,Robert D; Raskin,Ilya (1997): Metal accumulation by aquacultured seedlings of Indian mustard. Environ. Sci. Technol. 31, 1636-1644.

2675. Miller,Glenn C (1993): Treatment of acid mine drainage using waste agricultural products. Propsal submitted 11/12/93 for funding through the Nevada Agricultural Experiment Station.

2677. Jeffers,TH; Bennett,PG; Corwin,RR (1992): Wastewater remediation using bio-fix bead technology. In: Proceedings of the Second International Conference on Environmental Issues and Waste Management in Energy and Minerals Production. (Ed: Singhal) Balkema, Rotterdam, 1379-1387.

2781. de Vegt,AL; Bayer,HG; Buisman,CJ (1997): Biological sulfate removal and metal recovery from mine waters. (Preprint, 97-93.) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO. 5 pages.

2874. Kuyucak,Nural; St-Germain,Pascale (1994): In situ treatment of acid mine drainage by sulfate reducing bacteria in open pits: Scale-up experiences. To be presented at The International Land Reclamation and Acid Mine Drainage Conference, April 1994, Pittsburgh, PA.

2879. Eger,Paul; Wagner,Jon (1995): Sulfate reduction for the treatment of acid mine drainage: Long term solution or short term fix? In: Proceedings Sudbury '95 Conference on Mining and the Environment, Sudbury, Ontario, May 28-June 1, 1995. (:),, .

2927. Rhumbla,DK; Keefer,RF; Singh,RN (1988): Selenium Uptake by Alfalfa and Wheat Grown on a Mine

Spoil Reclaimed with Fly Ash. In: Mine Drainage and Surface Mine Reclamation. Vol. Volumn II. (Information Circular 9184) (Ed: Unknown)
2976. Unknown (1992): Bunker Hill Superfund Site. RI/FS Tecnical Memorandum.
3117. Anonymous (1991): Metal mine drainage may also be treatable. Technololgy Transfer Update (US Bureau of Mines), 1,3.
3119. Bureau of Mines (Ed.) (1990): Removal of heavy metals from LTV Steel Mining Company water using bio-fix beads. (Cooperative Work Performed Under Memorandum of Agreement between LTVSMCo and the Bureau of Mines) Bureau of Mines, Salt Lake City Reserach Center, US Dept. of the Interior, . 13 pages.
3120. Kalin,M (1985): The Chara Process Biological Economization of Mill Effluent Treatment Potential Applications and Preliminary Results. Boojum Reserach Limited, Toronto, Ontario. 49 pages.
3123. Lan,Chongyu; Chen,Guizhu; Li,Liuchun; Wong,MH (1992): Use of cattails in treating wastwater from a Pb/Zn mine. Environmental Management 16(1), 75-80.
3124. Cordell,CE; Marx,DH; Caldwell,C (1991): Operational application of specific ectomycorrhizal fungi in mineland reclamation. In: 1991 National Meeting of the American Society for Surface Mining and Reclamation. (Durango, CO, May 14-17, 1991) (:),, 641-648.
3129. de Vegt,AL; Bayer,HG; Buisman,CJ (1998): Biological sulfate removal and metal recovery from mine waters. Mining Engineering 50(November), 67-70.
3256. Thompson,Leslie C (1990): Biological field treatment applications in gold heap leach closures. In: Squaw Valley 90. (:),, 333-337.
3340. Rice,Phillip A; Rabolini,Franco (1800): Biological treatment of acid mine water. In: Unknown. (:),, 293-306.
3518. Canty,M (1999): Overview of sulfate-reducing bacteria demonstration project under the mine waste technology program. Mining Engineering 51(June), 93-99.
3535. Gould,WD; Bechard,G; Lortie,L (1994): The nature and role of microorganisms in the tailings environment. Chap. 7. In: Short Course Handbook on Environmental Geochemistry of Sulfide Mine-Wastes. Vol. 22. (Waterloo, Ontario, May 1994) (Eds: Jambor,JL; Blowes,DW) (Short Course Handbook.) Mineralogical Society of Canada, Ontario, Canada, 185-199.
Sud95 Bechard, G. et al. (1995) Microbial treatment of acid mine drainage at Halifax International Airport.
Sud95 Davis, B.S. et al. (1995) Acidophilic bacteria, acid mine drainage and Kidd Creek Mines tailings.
Sud95 Fyson, a. et al. (1995) Microbially-mediated metal removal from acid mine drainage.

c. Electrochemical

1622. Kelsh,Dennis J (1990): Tailings pond dewatering and consolidation by electroosmosis/electrophoresis. Chap. 27. In: Mining and mineral processing wastes. (Proc. Western Regional Symposium on Mining and Mineral Processing Wastes, Berkeley, CA, May 30-June 1) (Ed: Doyle,Fiona M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 221-228.
3674. ENPAR Technologies,Inc (Ed.) (1998): Electrochemical wastewater treatment applications in the metal mining industry. ENPAR Technologies, Inc., Ontario, Canada. 20 pages.
Pitt94 Shelp, G. et al. (1994) A demonstration of the feasibility of treating acid mine drainage by an in situ electrochemical method. V2.
Sud95 Kwong, Y.T.J. (1995) Influence of galvanic sulfide oxidation on mine water chemistry
Sud95 Shelp, G. et al. (1995) Cathodic protection of a weathering ore body.
Sud99 Lin, M. et al. (1999) Electrochemical treatment of sulfide tailings a laboratory study. V2.

d. Filtration/Membranes

801. Daellenbach,CB; Nilsen,DN (1800): Metal extraction from aqueous solutions with liquid emulsion membranes. Chap. 12. In: Inter-American Conference on Materials Technology. (Ed: Unknown) Unknown, Unknown, 1-8.
2177. Awadalla,FT; Hazlett,JD (1992): Application of membranes for the treatment of mining and metallurgical effluents. In: Waste Processing and Recycling in Mining and Metallurgical Industries. (Eds: Rao,SR; Amaratunga,LM; Boateng,DAD; Chalkley,ME) Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 87-103.
2306. Raghuraman,Bhavani; Tirmizi,Neena; Wiencek,John (1994): Emulsion liquid membranes for

wastewater treatment: Equilibrium models for some typical metal-extractant systems. Environ. Sci. Technol. 28(6), 1090-1098.

Tmw97 Stewart, D. et al. (1997) Utilization of a ceramic membrane for acid mine drainage treatment.

e. Flotation

45 Pavlica, J.J. (1974) Electrochemistry of pyrrhotite in flotation. M.Sc. Thesis, U of MN, 112p.

46 Iwasaki, I. (1953) Flotation characteristics of pyrrhotite. M.Sc. Thesis, U of MN, 62p.

1654. Benn,FW; Cornell,WL (1992): Removal of heavy metals from Missouri Lead Mill tailings by froth flotation. Chap. 12. In: Emerging process technologies for a cleaner environment. (Proc. Symposium on Emerging Process Technologies for a Cleaner Environment, February 24-27, Phoenix, Arizona) (Eds: Chander,S; Richardson,PE; El-Shall,H) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 81-85.

1655. Klimpel,Richard R (1992): Some uses of froth flotation for metal recovery from waste streams. Chap. 13. In: Emerging process technologies for a cleaner environment. (Proc. Symposium on Emerging Process Technologies for a Cleaner Environment, February 24-27, Phoenix, Arizona) (Eds: Chander,S; Richardson,PE; El-Shall,H) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 87-91.

1760. Anonymous (1989): Tailings: Drained or contained? E&MJ Unknown, 38-39.

2265. Brown,H; Skousen,J; Renton,J (1994): Floc generation by chemical neutralization of acid mine drainage. Green Lands 24(1), 44-51.

2314. Brown,Harry (1994): Volume and composition of flocs from chemical neutralization of acid mine drainage. Green Lands 24(2), 30-35.

2917. Meyerhofer,Paul F; Bench,Bryant (1983): Bench Scale Treatability Study of Acid Mine Drainage. In: Environmental Engineering. (Eds: Medine,Allen; Anderson,Michael) (1983 National Conference Proceedings of the ASCE Specialty Conference, Boulder, Colorado, July 6-8, 1983.) American Society of Civil Engineers, New York, New York, 471-478.

3272. Environmental Protection Agency (1993): Cyanide detoxification: INCO sulfur dioxide/air process. US Envivironmental Protection Agency, Crystal City, VA.

f. Ion Exchange

180. Jeffers,TH; Gritton,KS; Bennett,PG; Seidel,DC (1987): Recovery of cobalt from spent copper leach solution using continuous ion exchange. Bu Mines RI 9084, 17 pp.

275. Ceazan,Marnie L (1987): The role of cation exchange in the transport of ammonium and nitrate in a sewage-contaminated aquifer. Ground Water 25(5), 614.

Sud95 Riveros, P.A. (1995) Applications of ion exchangers to the treatment of acid mine drainage.

Sud95 Robertson, A.; Rohrs, R.G. (1995) Sulfate removal of acid mine drainage water after lime treatment.

g. Leaching

487 Illman, D. (1993) Waste acid recovery system cited for technoloty transfer. C&EN 71(14), 27.

488 Hammen, R.F.; Pang, D.C.; et al. (1993) Acid mine water processing and metal recovery by fast solid phase extraction. Mining Eng. 56-65.

532. McClelland,Gene E (1991): Laboratory scale heap detoxification. Heap & Dump Leaching 6(4, December), 1-8.

711 Steele, D.K.; Gritton, K.S. (1991) Metal recovery from acid-leach processing of arsenic-containing copper wastes.

718 Collins, M.J. et al. (1988) The behaviour and control of arsenic in the pressure oxidation of uranium and gold feedstocks.

720 Ramadorai, G.; Mishra, R.K. (1988) Roasting of arsenical gold and silver-bearing minerals.

721. Stefanakis,M; Hassapis,D; Demetriades,D; Kontopoulos,A (1988): Dearsenifying roasting and gold extraction from a refractory pyrite concentrate.

723 Robins, R.G. (1988) Arsenic hydrometallurgy.

726. Stefanakis,M; Kontopoulos,A (1988): Production of environmentally acceptable arsenites-arsenates from solid arsenic trioxide.

731. Hopkin,W (1988): The problem of arsenic disposal in nonferrous metals extraction.

1219. Cassiday,MW; Cox,TJ; Domfeh,IA; Stalker,Ian; Jaczkowski,BM (1992): The Ashanti (Ghana) heap

leach - Treatment of a decomposed schist in a tropical environment. Heap & Dump Leaching 7(1, January), 4-8.

1626 Gritton, K.S. (1990) Acid leach processing of an arsenic-containing copper waste.

1627 York, D.A.; Aamodt, P.L. (1990) Remediation of contaminated soil using heap leach mining technology.

1656 Taylor, P.R. et al. (1992) Extraction of lead, zinc, and silver from river bed tailings by ferric chloride.

1732 Fleming, S.P.; Cho, E.G. (1992) Leaching of nickel and cobalt from acid mine drainage sludge.

2525 Kurtz, J.P. (1800) Clay problems encountered in gold heap leaching.

2532 Loroesch, J. et al. (1989) Developments in gold leaching using hydrogen peroxide.

2544 Greaves, J.N. et al. (1990) The recovery of gold from refractory ores by the use of carbon-in-chlorine leaching.

h. Neutralization

805. Eychaner,James H; Stollenwerk,Kenneth G (1985): Neutralization of acidic ground water near Globe, Arizona. In: Groundwater Contamination and Reclamation. Vol. 85-2. (August) (Ed: Unknown) (Technical Publication Series.) American Water Resources Association,, 141-148.

932. Water Pollution Control Directorate Staff (1975): Mine and Mill Wastewater Treatment. Environment Protection Service, Environment Canda, Unknown.

1093. Cullen,GV (1976): Extraction of metals from effluents by calcium loaded brown coal and related materials. Institute of Materials Research, Department of Metallurgy, University of Melbourne.

1289. Firlotte,FW; Gelinas,P; Knapp,R; McMullen,J (1991): Acid drainage treatment at La Mine Doyon: Evolution and future direction. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 4. (Ed: MEND Program) Quebec Mining Association, Ottawa, 119-139.

1346. Jaynes,DB (1991): Modeling acid mine drainage from reclaimed coal stripmines. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. (Ed: MEND Program) Quebec Mining Association, Ottawa, 191-209.

1375. Aljoe,William W; Hawkins,Jay W (1991): Hydrologic characterization and in-situ neutralization of acidic mine pools in abandoned underground coal mines. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 69-89.

1476. Ackman,TE; Hustwit,CC (1988): Aeration efficiency of the in-line aeration and neutralization system. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 403.

1646. Skousen,JG (1991): An evaluation of acid mine drainage treatment systems and costs. Chap. 24. In: Environmental Management for the 1990's. (Proc. Symposium on Environmental Management for the 1990's, Denver, CO, February 25-28) (Eds: Lootens,Douglas J; Greenslade,William M; Barker,James M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 173-178.

1697. Kimball,Briant A; Broshears,Robert E; McKnight,Diane M; Bencala,Kenneth E (1994): Effects of instream pH modification on transport of sulfide-oxidation products. Chap. 16. In: Environmental geochemistry of sulfide oxidation. (ACS Symposium Series 550; Symposium at 204th National Meeting of the ACS, Washington, DC, Aug. 23-28) (Eds: Alpers,Charles N; Blowes,David W) American Chemical Society, Washington, DC, 224-243.

2290. Nawrot,JR; Warburton,DB (1987): Guidelines for slurry reclamation alternatives. In: Proc. National Symposium on Mining Hydrology, Sedimentology and Reclamation. (Conference held at Univeristy of Kentucky, Lexington, KY, Dec 7-11) (Eds: Unknown; Samuel,DE; Hill,JB) Cooperative Wildlife Research Laboratory, Sourthern Illinois University, Carbondale, IL, 277-283. (N)

3233. Struhsacker,Debra W; Smith,Adrian (1988): Cyanide neutralization and reclamtion requirements for heap leach projects. In: 1988 Symposium on Mining, Hydrology, Sedimentology, and Reclamation. (:) University of Kentucky, Lexington, KT, 189-198.

3235. Dreisinger,David (1989): Environmental issues in the aqueous processing of gold. JOM (December), 36-47.

Tmw99 Pucik, L. et al. (1999) Bi-phasic neutralization of evapo-concentrated acid mine drainage. pg 493.

Ammonia

323. Forward,FA; Mackiw,VN (1955): Chemistry of the ammonia pressure process for leaching Ni, Cu, and Co from Sherritt Gordon Sulphide Concentrates. Journal of Metals (March), 457-463.

807. Faulkner,Ben B; Skousen,Jeff (1800): Using ammonia to treat mine waters. Green Lands, 33-38.

2880. Skousen,Jeff; Lilly,Ron; Hilton,Tiff (1993): Special chemical for treating acid mine drainage. Green Lands (Summer), 34-41.

Lime

593. Ziemkiewicz,Paul (1992): Director's Column. Minelands 4(1, Summer), 1.

614. Sverdrup,Harald U; Warfvinge,Per G; Fraser,James (1985): The dissolution efficiency for different stream liming methods and technologies. Vatten 41(March), 155-163.

616. Rosseland,Bjorn Olav; Skogheim,Odd K (1984): Attempts to reduce effects of acidification on fishes in Norway by different mitigation techniques. Fisheries 9(1, January - February), 10-16.

617. Poissant,Sharon A; Caruccio,Frank T (1986): The occurrence and viability of *Thiobacillus ferroxidans* under varied geochemical conditions in Upshur and Lewis Counties, West Virginia. In: 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation. (Symposium held December 8-11) (Ed: University of Kentucky) University of Kentucky, Lexington, Kentucky, 141.

619. Britt,Douglas; Fraser,James E (1800): Effectiveness and uncertainties associated with the chemical neutralization of acidified surface waters. Unknown Unknown, 96-103.

630. Fraser,James E; Britt,Douglas L (1982): Liming of Acidified Waters: A Review of Methods and Effects on Aquatic Ecosystems. (FWS Contract Number 14-16-0009-82-013) General Research Corporation, McLean, VA. 187 pages.

631. Fraser,James E; Britt,Douglas L; Kinsman,John D (1985): APMP Guidance Manual: Volume II: Liming Materials and Methods. (Biological Report 80 (40.25): Air Pollution and Acid Rain Report No 25) International Science & Technology, Inc., Reston, Virginia. Unknown pages.

990. Unknown (1989): Aquatic Liming - Surface Water Improvement Program; Acid Mitigation Technologies. Unknown, Unknown. 17 pages.

1081. Runnells,Donald D; Rampe,John J (1989): Natural clean-up of a stream contaminated by mine and mill wastes: A reaction analogous to liming in water treatment. In: Water-Rock Interaction WRI-6. (Proc. 6th International Symposium, Malvern, UK) (Ed: Miles,Douglas L) A.A.Balkema, Rotterdam, Netherlands, 597-600.

1217. Ackman,Terry E; Kleinmann,Robert LP (1991): An in-line system for treatment of mine water. International Mine Waste Management News 1(3, October), 1-4.

1927. Sal'nikova,EO; Perederii,OG; Pushkarev,VV (1979): Investigation of methods of purifying acidic mine waters of undertakings of the copper subdivision. Plenum Publishing Coporation.

2176. Nyavor,K; Egiebor,NO (1992): Arsenic and sulphur emission control in the pretreatment of a secondary refractory gold concentrate by lime agglomeration roast. In: Waste Processing and Recycling in Mining and Metallurgical Industries. (Eds: Rao,SR; Amaratunga,LM; Boateng,DAD; Chalkley,ME) Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 75-83.

2859. Anonymous (Ed.) (1992): Iron Mountain Mine Superfund site: EPA announces proposed plan for cleanup of Boulder Creek contaminant sources. Environmental Protection Agency, San Fransisco, CA. 15 pages.

2954. Stilwell,Chuck (1994): Stream Channel Restoration and Mine Waste Management Along the Upper Clark Fork River. In: Mine Design, Operations & Closure Conference: Mining and the Environment. (Ed: Unknown) Atlantic Richfield Company, Unknown, 1-24.

3349. Draper,John C (1800): Mine drainage treatment experience. In: Unknown. (:),, 415-422.

Sud95 Kuyucak, N. et al. (1995) Improved lime neutralization process.

Sud95 Mitchell, P.B.; Atkinson, K. (1995) The treatment of acid rock drainage: A preliminary study of enhanced lime treatment by the co-application of soluble sodium silicate.

Van97 Poirier, P.J.; Roy, M. (1997) Acid mine drainage characterization and treatment at La Mine Doyon (Quebec). V4.

Van97 V4. Spotts, E. et al. (1997) Determination of runoff metal loading from reclaimed and unreclaimed tailings.

Van97 Zinck, J.M. (1997) Acid mine drainage treatment sludges in the Canadian mineral industry: Physical, chemical, mineralogical and leaching characteristics. V4.

Tmw98 Ford, R.C. et al. (1998) Stability of water treatment sludge, Climax Mine, Colorado Part 1. Chemical and mineralogical properties.

Tmw98 Ford, R.C. et al. (1998) Stability of water treatment sludge, Climax Mine, Colorado Part 2. Leaching characteristics.

Limestone/dolomite

346. Rivett,LS; Oko,UM (1971): Tailings disposal, generation of acidity from pyrrhotite and limestone neutralization of wastewater at Falconbridge's Onaping Mines. The Canadian Mining and Metallurgical (CIM) Bulletin, 108-113.

599. Pearson,Frank H; McBride,Stephen J (1988): Cost-effective neutralization by crusted limestone and conventional reagent. In: 1988 Symposium on Mining, Hydrology, Sedimentology and Reclamation. (Ed: University of Kentucky) University of Kentucky, Lexington, Kentucky, 67-72.

600. Pearson,Frank H; McDonnell,Archie J (1978): Limestone packed tumbling drums for acidity reduction. J. Water Pollut. Control Fed. Unknown(April), 723-733.

602. Pearson,Frank H; McDonnell,Archie J (1975): Limestone barriers to neutralize acidic streams.' Journal of the Environmental Engineering Division Unknown(EE3), 425-440.

603. Pearson,Frank (1988): Removal of Copper from Acidic Water in a Flum Packed with Crushed Limestone. In: Fifth Annual Hazardous Material Management Conference and Exposition. (Sponsored by Association of Bay Area Governments) (Ed: Unknown) Unknown, Unknown, 11.

604. Pearson,Frank; McBride,Stephen; Batcheler,Norman (1982): Decarbonation of limestone-treated mine drainage. Journal of the Environmental Engineering Division 108(EE5, Proceedings of the American Society of Civil Engineers, October), 957-972.

605. Pearson,Frank H; McDonnell,Archie J (1975): Use of crushed limestone to neutralize acid wastes. Journal of the Environmental Engineering Division 100(EE1, February), 139-158.

620. West Virginia (1986): Acid Water Studies. Four Performance Reports; two from July 1, 1985 through June 30, 1986 and two from July 1, 1986 through June 30, 1987; Project Number F-24-R-5 and F-24-R-6.

632. Driscoll,Charles T; White,Jeffrey R; Schafran,Gary C; Rendall,John D (1982): $CACO_3$ Neutralization of acidified surface waters. Journal of the Environmental Engineering Division Unknown(EE6, December), 1128-1145.

991. Wentzler,TH; Aplan,FF (1992): Neutralization reactions between acid mine waters and limestone. In: Emerging Process Technologies for a Cleaner Environment. (Eds: Chander,S; Richardson,PE; El-Shall,H) Cushing-Malloy, Inc., Ann Arbor, MI, 149-160.

1477. Stokowski,SJ Jr; Gilbert,RR (1988): Treatment of acidic coal refuse by addition of crushed-stone pond screenings. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 403.

1501. Lapakko,Kim; Antonson,David (1990): Treatment of waste rock drainage with limestone beds. In: Acid mine drainage: Designing for closure. (Presented at GAC/MAC Joint Annual Meeting in Vancouver, May 16-18) (Eds: Gadsby,John W; Malick,James A; Day,Stephen J) BiTech Publishers Ltd., Vancouver, BC, 273-283.

1916. Bituminous Coal Research Inc. (1970): Optimization and development of improved chemical techniques for the treatment of coal mine drainage. (Studies on limestone treatment of acid mine drainage.) U.S. Department of the Interior, Washington, DC. 96 pages.

1917. Pearson,Frank H; McDonnell,Archie J (1974): Chemical kinetics of neutralization of acidic water by crushed limestone. In: Water resources problems related to mining. (Proc. No. 18) (Ed: American Water Resources Association) American Water Resources Association, Unknown, 85-98.

1918. Hill,Ronald D; Wilmoth,Roger C (1970): Limestone treatment of acid mine drainage. Presented at 1970 Society of Mining Engineers Meeting.

1930. Rivett,LS; Oko,UM (1977): Tailings disposal, generation of acidity from pyrrhotite and limestone neutralization of wastewater at Falconbridge's Onaping Mines. The Canadian Mining and Metallurgical (CIM) Bulletin 64(712), 108-113. (N)

2490. Hammack,RW; Edenborn,HM; Dvorak,DH (1994): Treatment of water from an open-pit copper mine using biogenic sulfide and limestone: A feasibility study. Water Research 28, 2321-2329.
3339. Wilmoth,Roger C; Scott,Robert B; Hill,Ronald D (1800): Combination limestone-lime treatment of acid mine drainage. In: Unknown. (:),, 244-265.
3342. Ford,Charles T (1800): Developemnt of a limestone treatment process for acid mine drainage. In: Unknown. (:),, 266-291.
3346. Wilmoth,Roger C; Scott,Robert B (1800): Neutralization of high ferric iron acid mine drainage. In: Unknown. (:),, 66-113.
3347. Holland,Charles T; Berkshire,Robert C; Golden,David F (1800): An experimental investigation of the treatment of acid mine water containing high concentrations of ferrous iron with limestone. In: Unknown. (:),, 52-65.
3348. Ford,Charles T (1800): Selection of limestones as neutralizing agents for coal mine water. In: Unknown. (:),, 27-51.
3364. Anonymous (Ed.) (1986): Performance report: West Virigina, Acid Water Studies., .
3366. Erie Mining Company (Ed.) (1800): Seep 3 effluent treatment with limestone., .

i. Precipitation

582. Huang,Hsin-Hsiung; Shi,Yibin; Gu,Haiyang (1992): The Chemical Precipitation Treatment Processes for Acid Mine Drainage at the Berkeley Pit. Department of Metallurgical Engineering Montanta Tech, Butte, Montanta. 30 pages.
723. Robins,RG (1988): Arsenic hydrometallurgy (plenary). Chap. 3. In: Proc. 1988 TMS Annual Meeting and Exhibition: Arsenic Metallurgy--Fundamentals and Applications Symposium. (Symposium held at Phoenix, AZ, January 25-29) (Eds: Reddy,RG; Hendrix,JL; Queneau,PB) The Metallurgical Society, Inc., Warrendale, PA, 215-247.
861 Pahlman, J.E.; Khalafalla, S.E. (1800) Use of lignochemicals and humic acids to remove heavy metals from process waste streams.
1337 Kondos, P.D. et al. (1991) Studies on the removal of heavy metals from acidic mineral effluents.
1703. Alpers,Charles N; Nordstrom,D Kirk; Thompson,J Michael (1994): Seasonal variations of Zn/Cu ratios in acid mine water from Iron Mountain, CA. Chap. 22. In: Environmental geochemistry of sulfide oxidation. (ACS Symposium Series 550; Symposium at 204th National Meeting of the ACS, Washington, DC, Aug. 23-28) (Eds: Alpers,Charles N; Blowes,David W) American Chemical Society, Washington, DC, 324-344.
1909 Permutit (1977) SULFEX: Heavy metals waste treatment process.
1911 Larsen, H.P.; Ross, L.W. (1976) Two-stage process chemically treats mine drainage to remove dissolved metals.
1912. Pugsley,EB; Cheng,CY; Updegraff,DM; Ross,LW (1971): Removal of heavy metals from mine draiange in Colorado by precipitation. In: Chemical engineering: Progress symposium series. (Ed: Unknown) Unknown, Unknown, 75-85.
1920. Ross,Laurence W (1973): Removal of heavy metals from mine drainage by precipitation. (EPA-670/2-73-080) U.S. Environmental Protection Agency, Washington, DC. 64 pages.
2174. Rao,SR; Finch,JA (1992): Resource recovery from acid mine drainage; bench-scale studies of two precipitation options. In: Waste Processing and Recycling in Mining and Metallurgical Industries. (Eds: Rao,SR; Amaratunga,LM; Boateng,DAD; Chalkley,ME) Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, Quebec, 3-11.
Sud99 Mitchell, P.; Wheaton, A. (1999) From environmental burden to natural resource: New reagents for cost-effective treatment of and metal recovery from acid rock drainage. V3.

Gypsum

1357 Gussmann, H.W. et al. (1991) The treatment of underground mine waters for the removal of calcium and sulfates by a GYP-CIX process.

Oxides

718. Collins,MJ; Berezowsky,RM; Weir,DR (1988): The behaviour and control of arsenic in the pressure oxidation of uranium and gold feedstocks. Chap. 2. In: Proc. 1988 TMS Annual Meeting and Exhibition: Arsenic Metallurgy--Fundamentals and Applications Symposium. (Symposium held in

Pheonix, AZ, January 25-29) (Eds: Reddy,RG; Hendrix,JL; Queneau,PB) The Metallurgical Society, Inc., Warrendale, PA, 115.
1738 Mehta, R.K. (1992) Chemoremediation of acid mine drainage by controlled ferrite coprecipitation and magnetic separation.
2326 LeGendre, G.R.; Runnells, D.D. (1975) Removal of dissoled molybdenum from wastewaters by precipitates of ferric iron.
Pitt94 Yang, K. et al. (1994) Removal of heavy metal ions and synthesis of ferrite from acid mine drainage by modified ferrite coprecipitation. V2.

Sulfide

149. Industrial Environmental Research Laboratory (Cincinnati Ohio) (1980): Control and treatment technology for the metal finishing industry: Sulfide precipitation. (EPA 625/8-80-003) (Summary report (United States, Environmental Protection Agency).) Industrial Environmental Research Laboratory, Cincinnati, Ohio. 54 pages.
230. Daskalakis,Kostas D; Heiz,George R (1992): Solubility of CdS (Greenockite) in Sulfidic Waters at 25° C. Environ. Sci. Technol. 26, 2462-2466.
3108. Schulach,Richard M; Epstein,Arthur C (1977): Treatment of Metal Finishing Wates by Sulfide Precipitation. (EPA-600/2-77-049) US Environmental Protection Agency, Cincinnati, OH. 89 pages.
Pitt94 Hammack, R.W. et al. (1994) Bench-scale test to selectively recover metals from metal mine drainage using biogenic H_2S. V1.
Pitt94 Rao, S.R. et al. (1994) Prospect of metal recovery/recycle from acid mine drainage. V1.
Van97 Diaz, M.A. et al. (1997) Consecutive hydroxide-sulfide precipitation treatment of acid mine drainage. V3.
Van97 Rowley, M.V. et al. (1997) Site demonstration of the biosulfide process at the former Britannia Mine. V4.

j. Reactive Barriers

3437. Benner,SG; Blowes,DW; Gould,WD; Herbert,RB Jr; Ptacek,CJ (1999): Geochemistry of a permeable reactive barrier for metals and acid mine drainage. Environ. Sci. Technol. 33, 2793-2799.
Van97 Waybrant, K.R. et al. (1997) A geochemical and mineralogical investigation of porous reactive walls for the prevention of acid mine drainage. V4.
Sud99 Martin, T.A.; Kempton, J.H. (1999) In situ stabilization of metal-contaminated ground water. V2.
Sud99 McGregor, R. et al. (1999) Remediation of heavy metal contaminated ground water using a porous reactive wall within an urban setting. V2.
Sud99 McRae, W.T. Che et al. (1999) In situ removal of arsenic from ground water using permeable reactive barriers: a laboratory study. V2.
Sud99 Mercier, L. et al. (1999) Functionalized ordered mesoporous materials for heavy metal ion trapping: an emerging environmental technology. V2.
Sud99 Revazyan, R.H. (1999) Technological ecosystems and creation of anti-filter barriers preventing pollution of ground water. V3.

k. Reverse Osmosis

1185. Blackshaw,G Lansing; Pappano,Alfred W; Thomas,Garth E Jr; Cheng,Shun-Yung (1983): Project Summary: Pilot Plant Treatment of Acid Mine Drainage by Reverse Osmosis. (S2-83-031) U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Cincinnati, OH. 8 pages.
Sud99 Berg, G.; Arthur, B. (1999) Proposed mine water treatment in Wisconsin. V2.

l. Sludge treatments

1250. Chiado,Eric D; Bowders,John J; Sencindiver,John C (1988): Phosphatic clay slurries for reducing acid mine drainage from reclaimed mine sites. In: Mine Drainage and Surface Mine Reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, PA, 44-75.
1512. Higgs,Thomas W (1990): ARD Treatment plant sludge - Chemical stability and disposal considerations. In: Acid mine drainage: Designing for closure. (Presented at GAC/MAC Joint Annual Meeting in Vancouver, May 16-18) (Eds: Gadsby,John W; Malick,James A; Day,Stephen J) BiTech

Publishers Ltd., Vancouver, BC, 427-440. (N)
1533. Vachon,D; Siwik,RS; Schmidt,J; Wheeland,K (1987): Treatment of acid mine water and the disposal of lime neutralization sludge. In: Proc. acid mine drainage seminar/workshop. (Seminar held in Halifax, Nova Scotia, March 23-26) (Ed: Environment Canada) Environment Canada, Ottawa, 537-564.
1908. Ackman,TE (1800): Sludge disposal from acid mine drainage treatment. U.S. Bureau of Mines, Pittsburgh, PA. 23 pages.
Sud95 Murdock, D.J. et al. (1995) Treatment of acid mine drainage by the high density sludge process
Sud95 Orava, D. et al. (1995) Evaluating alternative long-term strategies for treatment of AMD.
Sud99 Aube, B.C. (1999) Innovative modifications to high density sludge process. V3.

m. Sorption

806 Jeffers, T.H.; Groves, R.D. (1985) Using solvent-impregnated carbon to recover copper from oxidized mill tailings.
2838. Lapakko,Kim A; Strudell,James D; Eger,A Paul (1986): Low-cost removal of trace metals from copper-nickel mine stockpile drainage. Volume II, Trace metal sequestration by peat, other organics, tailings, and soils: A literature review. Bureau of Mines, . 45 pages.
Pitt94 Hubbard, K.L. et al. (1994) New functional polymers as sorbents for the selective recovery of toxic heavy metals from acid mine drainage. V2.
Tmw99 Gilbert, J.S. et al. (1999) Adsorption capabilities of clinoptilolite relating to acid mine drainage remediation. pg 515.
Sud99 Mercier, L. et al. (1999) Functionalized ordered mesoporous materials for heavy metal ion trapping: An emerging environmental technology. V2.

n. Trapazene

1336. Lovett,RJ; Ziemkiewicz,PF (1991): Trapzene for treatment of acid mine drainage. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. (Ed: MEND Program) Quebec Mining Association, Ottawa, 35-46.

o. Zeolites

802. Leppert,D (1990): Heavy metal sorption with clinoptilolite zeolite: Alternative for treating contaminated soil and water. Mining Engineering, 604-608.
1415. Vos,RJ; O'Hearn,TA (1993): Use of zeolite to treat acid rock drainage from Britannia minesite. In: Proc. 17th Annual British Columbia Mine Reclamation Symposium: Mine Reclamation "Building Confidence". (Ed: Sponsored by: Mining Association of British Columbia) The Ministry of Energy, Mines and Petroleum Resources, British Columbia, 223-232.
Pitt94 Schultze, L.E. et al. (1994) AMD cleanup using natural zeolites. V2.

A1.8. Hydrology/Groundwater

25. Morin,Kevin A; Cherry,John A (1988): Migration of acidic groundwater seepage from uranium-tailings impoundments, 3. Simulation of the conceptual model with application to seepage area A. Journal of Contaminant Hydrology 2(4), 323-342.
159. Rubin,Jacob; James,RV; Bahr,JM; Willis,C (1991): Solute Transport in the unsaturated zone. In: U.S. Geological Survey research in radioactive waste disposal - Fiscal Years 1986 - 1990. (Water Resources Investigations Report 91-4084. A summary of work done in part in cooperation with the U.S. Department of Energy) (Eds: Trask,NJ; Stevens,PR) U. S. Department of the Interior, U.S. Geological Survey, Denver, Colorado, 77-80.
160. Morin, K.A.; Cherry, J.A. (1988) Migration of acidic groundwater seepage from uranium-tailings impoundments. 3. Simulatin of the conceptual model with application to seepage area A. J. Contaminant Hydrology 2(4), 323-342.
216. Williams,BC; Lambeth,RH; Stewart,BM (1989): Determining heavy metal leaching and transport from abandoned mine wastes. In: Society of Mining Engineers: Preprint Number 89-25. (Ed: Society of Mining Engineers) Society of Mining Engineers, Littleton, Colorado, 1-10.
458. Rasmuson,Anders (1989): Modelling of Solute Transport in the Unsaturated Zone. (Report 3592) National Swedish Environmental Protection Board, Solna, Sweden. 65 pages.

613. Caruccio,Frank T; Geidel,Gwendelyn; Williams,Ray (1984): Induced Alkaline Recharge Zones to Mitigate Acidic Seeps. In: 1984 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation. (Symposium held December 2-7, 1984) (Ed: University of Kentucky) University of Kentucky, Lexington, Kentucky, 43-47.
633. Kettles,IM; Wyatt,PH (1985): Applications of till geochemistry in southwestern New Brunswich: Acid rain sensitivity and mineral exploration. Chap. 49. In: Current Research, Part B, Geological Survey of Canada. (Paper 85-1B) (Ed: Unknown) Unknown, Unknown, 413-422.
916. Muncy,Jack A (1989): Reclamation of abandoned manganese mines in southwest Virginia and northeast Tennessee. Paper presented at the joint meeting of the Canadian Land Reclamation Association and the American Society for Surface Mining and Reclamation, Calgary, Alberta, Canada, August 27-31.
922. Craze,Barry (1980): Mine waste pollution control at captains flat, New South Wales. In: Biogeochemistry of Ancient and Modern Environments. (Proc. 4th International Symposium on Environmental Biogeochemistry and Conference on Biogeochemistry in Relation to the Mining Industry and Environmental Pollution, Canberra, Australia 26 August-4 September 1979) (Eds: Trudinger,PA; Walter,MR; Ralph,BJ) Springer-Verlag, Berlin Heidelberg NY, 705-712.
923. Flora,Mark; Kunkle,Sam; Kimball,Dan (1987): Water pollution mitigation in two national park service units affected by energy and mining activities. In: Water Resources Related to Mining and Energy-Preparing for the Future. (November) (Ed: Unknown) American Water Resources Association, Unknown, 231-237.
924. Malone,David S; Walstrom,Janet S; Jarman,Ron (1987): Tar Creek: Diversion efforts toward an unpolluted future. In: Water Resoruces Related to Mining and Energy-Preparing for the Future. (Ed: Dworsky,RF) American Water Resources Association, Bethesda, Maryland, 299-308.
926. Jones,Kevin R (1987): Ground water monitoring and remediation at a tailings impoundment in northwest Montana. In: Water Resources Related to Mining and Energy-Preparing for the Future. (Ed: Dworsky,RF) American Water Resources Association, Bethesda, Maryland, 509-522.
1103. Huyakorn,Peter S; Ungs,Michael J; Mulkey,Lee A; Sudicky,Edward A (1987): A three-dimensional analytical method for predicting leachate migration. Ground Water 25(5), 588-598.
1253. Flynn,James P (1969): Treatment of Earth surface and sub-surface for prevention of acidic drainage from the soil. U.S. Patent Office Number 3,433,882.
1299. MEND Program (Ed.) (1991): Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 3. Quebec Mining Association, Ottawa, Ontario. 586 pages.
1323. Evaldi,Ronald D; Garcia,Rene (1991): Quality of South Fork Cumberland River near Stearns, Kentucky. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 3. (Ed: MEND Program) Quebec Mining Association, Ottawa, 417-434.
1348. St-Arnaud,LC (1991): Computer modelling for the evaluation of closure options. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. (Ed: MEND Program) Quebec Mining Association, Ottawa, 231-234.
1374. Hawkins,JW; Aljoe,WW (1991): Hydrologic characteristics of a surface mine spoil aquifer. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 47-68.
1404. Gozon,JS; Britton,RR; Spires,S; Ricca,VT; Zhang,W (1991): Computer aided dam site selection for acid mine drainage abatement. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 581-600.
1406. McCreadie,Hugh; Smith,Rod (1993): Groundwater quality evaluations of mines. In: Proc. 17th Annual British Columbia Mine Reclamation Symposium: Mine Reclamation "Building Confidence". (Ed: Sponsored by: Mining Association of British Columbia) The Ministry of Energy, Mines and Petroleum Resources, British Columbia, 87-97.
1442. Ackman,Terry E; Jones,J Richard (1988): Stream sealing to reduce surface water infiltration. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 232-239.
1514. Perrin,Chris J (1990): A bioassay for testing the effect of an operational dilution rate of treated acid

mine drainage on stream functioning. In: Acid mine drainage: Designing for closure. (Presented at GAC/MAC Joint Annual Meeting in Vancouver, May 16-18) (Eds: Gadsby,John W; Malick,James A; Day,Stephen J) BiTech Publishers Ltd., Vancouver, BC, 451-461. (N)

1542. Alderdice,Linda; Adams,John L; Eger,A Paul (1992): Managing the hydrologic impacts of mining on Minnesota's Mesabi Iron Range. In: Achieving land use potential through reclamation. (ASSMR9-92) (Ed: American Society for Surface Mining and Reclamation) American Society for Surface Mining and Reclamation, WV, 108-116.

1612. Strachan,Clinton L; Shepherd,Thomas A (1990): Design issues associated with reclamation of uranium tailings impoundments. Chap. 17. In: Mining and mineral processing wastes. (Proc. Western Regional Symposium on Mining and Mineral Processing Wastes, Berkeley, CA, May 30-June 1) (Ed: Doyle,Fiona M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 143-147.

1618. Joyce,Chris; Ryan,Peter (1990): Integrated environmental engineering for acid mine drainage control in Australia. Chap. 23. In: Mining and mineral processing wastes. (Proc. Western Regional Symposium on Mining and Mineral Processing Wastes, Berkeley, CA, May 30-June 1) (Ed: Doyle,Fiona M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 185-194.

1628. Haung,Hsin-Hsiung; Tahija,Dave (1990): Characteristics and treatment problems of surface and underground waters in abandoned mines at Butte, MO. Chap. 33. In: Mining and mineral processing wastes. (Proc. Western Regional Symposium on Mining and Mineral Processing Wastes, Berkeley, CA, May 30-June 1) (Ed: Doyle,Fiona M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 261-270.

1656. Taylor,Patrick R; Choi,Yeonuk; Cunningham,Lyle (1992): Extraction of lead, zinc, and silver from river bed tailings by ferric chloride. Chap. 14. In: Emerging process technologies for a cleaner environment. (Proc. Symposium on Emerging Process Technologies for a Cleaner Environment, February 24-27, Phoenix, Arizona) (Eds: Chander,S; Richardson,PE; El-Shall,H) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 93-98.

1680. Patterson,Robert JL (1989): Water management at Equity Silver Mines Ltd. Chap. 7. In: Water Management at Minesites. (Proc. 13th Annual British Columbia Mine Reclamation Symposium) (Eds: Mining Association of British Columbia; Ministry of Energy,Mines and Petroleum Resources; Ministry of Environment) Ministry of Energy,Mines and Petroleum Resources, Victoria, BC, 81-97.

1721. Evangelou,VP; Grove,JH; Phillips,RE (1982): Factors controlling water movement in acid spoils. In: 1982 Symposium on surface mining, hydrology, sedimentology, and reclamation. (University of Kentucky, Lexington, KY, December 5-10) (Eds: Graves,Donald H; DeVore,R William) University of Kentucky, Lexigton, KY, 5-9.

1775 Searle, R.T. (1800) Evaluation of pre- and post-project mitigation efforts of the Intermountain Power Project.

1882. Smith,KS; Ranville,JF; Macalady,DL (1991): Predictive modeling of copper, cadmium, and zinc partitioning between streamwater and bed sediment from a stream receiving acid mine drainage, St. Kevin Gulch, Colorado. In: U.S. Geological Survey Toxic Substances Hydorology Program; Proceedings of the technical meeting. (Eds: Mallard,GE; Aronson,DE) U.S. Geological Survey, Tampa, FL, 380-386. (N)

1885. Kimball,BA; Broshers,RE; Bencala,KE; McKnight,DM (1991): Comparison of rates of hydrologic and chemical processes in a stream affected by acid mine drainage. In: U.S. Geological Survey Toxic Substances Hydorology Program; Proceedings of the technical meeting. (Eds: Mallard,GE; Aronson,DE) U.S. Geological Survey, Tampa, FL, 407-412. (N)

1889. Eychaner,JH (1991): The Globe, Arizona, researach site; contaminants related to copper mining in a hydrologically integrated enviornment. In: U.S. Geological Survey Toxic Substances Hydorology Program; Proceedings of the technical meeting. (Eds: Mallard,GE; Aronson,DE) U.S. Geological Survey, Tampa, FL, 439-447. (N)

1931. Barthauer,GL; Kosowski,ZV; Ramsey,JP (1971): Control of mine drainage from coal mine mineral wastes: Phase I Hydrology and related experiments. (Water Pollution Control Research Series Project No. 14010DDH) Environmental Protection Agency, Washington, DC. 148 pages.

1932. Fuller,Richard H; Shay,Johnevan M; Ferreira,Rodger F; Hoffman,Ray J (1978): An evaluation of

problems arising from acid mine drainage in the vicinity of Shasta Lake, Shasta County, California. (Water-Resources Investigations 78-32) U.S. Geological Survey, Menlo Park, CA. 39 pages.
2129. Rowley,WJ (1975): Part A: Water pollution sources. In: A study of water pollution in the vicinity of Flin Flon, Manitoba. (Surveillance Report EPS 5-NW-75-7) (Ed: Environmental Protection Services) Environmental Protection Services, Canada, Intro-130+.
2130. Sergy,GA; Fallis,BW (1978): Part B: Effects on receiving waters. In: A study of water pollution in the vicinity of Flin Flon, Manitoba. (Surveillance Report EPS 5-NW-78-6) (Ed: Environmental Protection Services) Environmental Protection Services, Canada, Intro-In107.
2436. Hawkins,Jay W (1994): A statistical evaluation of remining abandoned coal mines to reduce the effluent contaminant load. International Journal of Surface Mining, Reclamation and Environment 8, 101-109.
2506. Herzog,David J; Forsgren,Frank M (1995): Evaluating the potential impacts of mine wastes on ground and surface waters. Mining Engineering 47(March), 254-256.
2753. Paulson,Anthony J; Balderrama,Robert; Zahl,Eric (1996): Treatment of fluvially deposited streamside mine waste: Material from Canyon Creek, Idaho. (9633) (Report of Investigations.) US Government Printing Office, Washington, DC. 58 pages.
2754. Paulson,Anthony J; Balderrama,Robert; Zahl,Eric; Cox,Ryan L (1996): Treatment of fluvially deposited streamside mine waste: Material from Nine Mile Creek, Idaho. (9631) (Report of Investigations.) US Government Printing Office, Washington, DC. 67 pages.
2851. Runnells,DD; Dupon,DP; Jones,RL; Cline,DJ (1998): Determination of natural background concentrations of dissolved components in water at mining, milling, and smelting sites. Mining Engineering 50(February), 65-71.
3038. Arnekleiv,JV; Storset,L (1800): Downstream effects of mine drainage on benthos and fish in a Norwegian river: a comparison of the situation before and after rehabilitation. Journal of Geochemical Exploration, Special Issue: Heavy metal aspects of mining pollution and its remediation 52(1 and 2, Eds: Allan,RJ; Salomons,W), 35-44.
3337. Hepworth,Malcolm T (1992): Remediate mine drainage with specially-prepared shredded scrap tires. Draft proposal subbitted by Malcolm Hepworth.
3457. Muller,Sean C (1997): Utilization of pyritic tailings to mitigate arsenic mobilization in groundwater. In: Tailings and Mine Waste '97. (:) Balkema, Rotterdam, 509-516.
3541. Blowes,DW; Ptacek,CJ; Jambor,JL (1994): Remediation and prevention of low-quality drainage from tailings impoundments. Chap. 13. In: Short Course Handbook on Environmental Geochemistry of Sulfide Mine-Wastes. Vol. 22. (Waterloo, Ontario, May 1994) (Eds: Jambor,JL; Blowes,DW) (Short Course Handbook.) Mineralogical Society of Canada, Ontario, Canada, 365-379.
Pitt94 Bird, D.A. et al. (1994) Development of a reaction path approach to modeling post-mining pit watergeochemistry.
Pitt94 Gabr, M.A. et al. (1994) Assessment of acid mine drainage remediation schemes on ground water flow regimes at a reclaimed mine site. V2.
Sud95 Bridwell, R.J.; Travis, B.J. (1995) Numerical simulation of acid mine drainage in a fully-coupled 3-D ground water flow and chemical transport model: Part I. field example and validation.
Sud95 Lefebvre, R.; Gelinas, P.J. (1995) Numerical modeling of AMD production in waste rock dumps.
Sud95 Nicholson, R.V. et al. (1995) An application of the WATAIL model to develop a management strategy for a pyrrhotite tailings impoundment.
Sud95 Rastogi, V. et al. (1995) Factors affecting ARD production: size and configuration of waste rock piles.
Sud95 Wunderly, M.D. et al. (1995) A multicomponent reactive transport model incorporating kinetically controlled pyrite oxidation.
Van97 Pollmer, K.; Eckart, M. (1997) Description of reaction- and transport processes in the zone of aeration of mine dumps. V4.
Tmw98 Jordan, D. et al. (1998) Geochemical transport modeling of tailings pore water.
Tmw98 Kolluru, V.S. et al. (1998) Integrated model to simulate the transport and fate of mine tailings in deep waters.
Sud99 Bennett, J.W.; Timms, G.P. (1999) The phenomenon of remnant heat in sulfidic waste rock dumps.

V1.
Sud99 Mayer, K.U. et al. (1999) The reactive transport model MIN3P: application to acid mine drainage generation and treatment-Nickel Rim mine site, Sudbury, Ontario. V1.
Sud99 Smolensky, J. et al. (1999) Oxygen transport processes in the Nordhalde of the Ronnenburg Mining District, Germany. V1.

A1.9. General Overviews & Miscellaneous

395. Wixson,Bobby G; Davies,Brian E (1985): Frontier technology for environmental clean-up. Chap. 4. In: Frontier Technology in Mineral Processing. (Eds: Spisak,John F; Jergensen,Gerald V,II) Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, NY, 33-42.
411. MSE,Inc (1992): Technology Reviews: Mine Waste Pilot Program. Vol. 1. (September 15, 1992; Activity 1, Appendix A; IAG ID No. DW89935117-01-0) MSE, Inc., Butte, MT. 105 pages.
412. Foote,M (1992): Mine Waste Pilot Program Activity 1: Issues Identification and Technology Prioritization Report. Vol. 1: Mobile Toxic Constituents - Water and Acid Generation. (September 1; IAG ID No. DW89935117-01-0) Montana College of Mineral Science and Technology and MSE, Inc., Butte, MT. 128 pages.
413. MSE,Inc (1992): Chemistry Review for Mine Waste Pilot Program. Vol. 1. (September 15; Activity 1; Appendix A;) MSE, Inc., Component Development and Integration Facility (CDIF), Butte, MT. 33 pages.
481. Wheeland,Kenneth G (1990): Overview of Noranda Research on AMD prevention and control. Presented at the Vancouver '90 GAC/MAC Annual Meeting, 16-18 May 1990.
484 Austin, G.S.; Brandvold, L.A.; Renault, J. (1993) Lead contamination at an old smelter site at Socorro, NM. Part 2--Laboratory tests. Mining Eng. 45, 396-401.
485 Austin, G.S.; Brandvold, L.A.; Hawley, J.W.; Renault, J. (1993) Lead contamination at an old smelter site at Socorro, NM: Part 1--Particle size and depth of contamination. Mining Eng. 45, 389-395.
487. Illman,Deborah (1993): Waste acid recovery system cited for technology transfer. C&EN 71(14, 5 April), 27.
612. Ladwig,Kenneth; Erickson,Patricia; Kleinmann,Robert LP (1800): Alkaline Injection: An Overview of Recent Work. In: Control of Acid Mine Drainage: Proceedings of a Technology Transfer Seminar. (Information Circular 9027) (Ed: Unknown) United States Department of the Interior, Unknown, 35.
629. Romano,Rosanna (1989): Dramatic resuce of a vital river. Green Lands Unknown(Fall), 9-12.
662. Smith,A; Barton-Bridges,J (1989): Some considerations in the prediction and control of acid drainage impact on groundwater from mining waste in North America. Groundwater and Mining (August), .
764. Wildeman,Thomas R; Ramirez R,Armando J (1976-1977): Chemical analysis of mine drainage waters. Chap. 16. In: Molybdenum in the Environment. Vol. 2. (Eds: Chappell,Willard R; Kellogg Petersen,Kathy) Marcel Dekker, Inc., New York, 739-752.
797. Haynes,Benjamin W (1990): Environmental technology research: A progress report. Minerals Today Unknown(May), 14-17.
798. Veith,David L; Kaas,L Michael (1988): Mineral-related waste management in the Bureau of Mines Environmental Technology Program. Proc. 1988 Symposium on Mining, Hydrology, Sedimentology and Reclamation, University of Kentucky, Lexington, KY, Dec. 5-9. 7-12.
817. Harries,JR; Ritchie,AIM (1986): The impact of rehabilitation measures on the physicochemical conditions within mine wastes undergoing pyritic oxidation. Chap. 7. In: Fundamental and Applied Biohydrometallurgy. (Proc. 6th International Symposium on Biohydrometallurgy in Vancouver, BC, Canada, August 21-24, 1985) (Eds: Lawrence,Richard W; Branion,Richard MR; Ebner,Hans G) Elsevier, Amsterdam, 341-351.
917. McAdoo,J Kent; Acordagoitia,Gary A; Harshfield,Mark A; Aarstad,Curt R (1988): Reducing resource impacts of mineral exploration and mining in northern Nevada. In: 1988 Symposium on Mining, Hydrology, Sedimentology and Reclamation. (Ed: University of Kentucky) University of Kentucky, Lexington, Kentucky,
1129. Haynes,Benjamin W (1992): Environmental technology research: The U.S. Bureau of Mines approach.

Proc. of the Successful Mine Reclamation Conference, Sparks, NV, May 19-22; 31-44.
1184. Borovsky,John P; Grigal,David F; Strassman,Ricki L (1983): Reclamation of Tailing Basins Resulting From Copper-Nickel Milling. U.S. Department of the Interior, Bureau of Mines, Minneapolis, MN. 147 pages.
1206. Ziemkiewicz,PF (1990): Advances in the prediction and control of acid mine drainage. Presented at 1990 Mining and Reclamation Conference and Exhibition, Charleston, West Virginia, April 23-26. p. 51-54.
1218. Per Age Beck,Veritas (1991): Acid mine drainage abatement in Norway. International Mine Waste Management News 1(3, October), 4-12.
1233. Jennett,J Charles; Wixson,Bobby G (1972): Problems in lead mining waste control. J. Water Pollut. Control Fed. 44(11, November), 2103-2110.
1247. Wildeman,Thomas (1800): Drainage from coal mines: Chemistry and environmental problems. In: Summary of Literature Regarding AMD Control Technologies. (Ed: Terry I. Mudder Environmental Services Ltd.) Times Limited, Redmond, WA, Unknown.
1248. Meek,F Allen Jr (1800): Assessment of acid preventative techniques employed at the Island Creek Mining Co. Tenmile site. In: Summary of Literature Regarding AMD Control Technologies. (Ed: Terry I. Mudder Environmental Services Ltd.) Times Limited, Redmond, WA, Unknown.
1251. Skousen,JG; Sencindiver,JC; Smith,RM (1987): A review of procedures for surface mining and reclamation in areas with acid-producing materials. Energy and Water Research Center, Morgantown,WV.
1252. Ziemkiewicz,PF; Stiller,AH; Rymer,TE; Hart,WM (1800): Advances in the prediction and control of acid mine drainage. Found in Summary of Literature Regarding AMD Control Technologies.
1259. Lapakko,Kim (1988): Prediction of acid mine drainage from Duluth Complex mining wastes in Northeastern Minnesota. In: Mine drainage and surface mine reclamation. Vol. 1: Mine water and mine waste. (Ed: Bureau of Mines) U.S. Department of Interior, Pittsburgh, 180-190.
1260. Lapakko,Kim (1988): Preoperational projection of metallic mine waste drainage quality. Chap. 17. In: Proc. International Conference on Control of Environmental Problems from Metal Mines. (Eds: State Pollution Control Authority; Federation of Norwegian Industries) State Pollution Control Authority, Norway, 12 p.
1273. Domvile,Serena (1992): Acid rock drainage - Review and assessment study. International Mine Waste Management News 2(2), 12-13.
1282. MEND Program (Ed.) (1991): Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 4. Quebec Mining Association, Ottawa, Ontario. 352 pages.
1296. Hornsby,JK; Graham,D; Link,K; Mullins,D (1991): Remote sensing to monitor uranium tailings sites - A review. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 4. (Ed: MEND Program) Quebec Mining Association, Ottawa, 255-274.
1332. MEND Program (1991): Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. Quebec Mining Association, Ottawa. 607 pages.
1343. Galbraith,DM (1991): The Mount Washington acid mine drainage reclamation project. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. (Ed: MEND Program) Quebec Mining Association, Ottawa, 145-161.
1344. Ese,Harald (1991): Acidic mine drainage from the Killingdal Mine Norway. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 2. (Ed: MEND Program) Quebec Mining Association, Ottawa, 163-172.
1370. MEND Program (Ed.) (1991): Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. Quebec Mining Association, Ottawa. 600 pages.
1382. Senft,Joseph P; Baker,Dale E (1991): Reclamation of a very acid mine waste site in Pennsylvania, USA. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 209-219.
1383. Ryan,Peter; Joyce,Chris (1991): Prevention and remediation of acid drainage from mine waste rock in Australia. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 221-245.

1384. Taxer,Eric J; Churchill,Jason J; Gill,Ranjit S (1991): A history of the Leviathan Mine pollution abatement project, Alpine County, California. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 247-265.

1385. Aubertin,Michel; Chapuis,Robert; St-Arneault,Claude; Barbera,Jean-Marc; Côté,Martin (1991): Caractérisation environnementale du ruisseau vauze sur le site norbec pour la conception d'amenagements correcteurs. In: Proc. 2nd International Conference on the Abatement of Acidic Drainage. Vol. 1. (Ed: MEND Program) Quebec Mining Association, Ottawa, 267-282.

1414. Price,William A; Tremblay,Gilles A (1993): An overview of acid mine drainage mitigation and test work in northwest Quebec. In: Proc. 17th Annual British Columbia Mine Reclamation Symposium: Mine Reclamation "Building Confidence". (Ed: Sponsored by: Mining Association of British Columbia) The Ministry of Energy, Mines and Petroleum Resources, British Columbia, 203-219.

1428. Backes,CA; Pulford,ID; Duncan,HJ (1988): Treatments to combat pyrite oxidation in coal mine spoil. In: Mine drainage and surface mine reclamation. (Ed: Bureau of Mines) U.S. Department of the Interior, Pittsburgh, 91-96.

1482 Gadsby, J.W. et al. (1990) Acid mine drainage: Designing for closure.

1498. Harries,John R; Ritchie,A Ian M (1990): Australian experience in controlling acid generation in mine waste rock dumps. In: Acid mine drainage: Designing for closure. (Presented at GAC/MAC Joint Annual Meeting in Vancouver, May 16-18) (Eds: Gadsby,John W; Malick,James A; Day,Stephen J) BiTech Publishers Ltd., Vancouver, BC, 231-240. (N)

1499 Lundgren, T.A. (1990) Bersbo - The first full scale project in Sweden to abate acid mine drainage from old mining activities.

1513. Patterson,Robert J (1990): Mine closure planning at Equity Silver Mines Ltd. In: Acid mine drainage: Designing for closure. (Presented at GAC/MAC Joint Annual Meeting in Vancouver, May 16-18) (Eds: Gadsby,John W; Malick,James A; Day,Stephen J) BiTech Publishers Ltd., Vancouver, BC, 441-449. (N)

1518. Environment Canada (Ed.) (1987): Proc. Acid Mine Drainage Seminar/Workshop. (Held in Halifax, Nova Scotia, March 23-26) Environment Canada, Ottawa. 615 pages.

1525. McCready,RGL (1987): A review of the physical, chemical and biological measures to prevent acid mine drainage: An application to the pyritic Halifax shales. In: Proc. acid mine drainage seminar/workshop. (Seminar held in Halifax, Nova Scotia, March 23-26) (Ed: Environment Canada) Environment Canada, Ottawa, 333-355.

1527. Bell,Alan V (1987): Prevention of acid generation in base metal tailings and waste rock. In: Proc. acid mine drainage seminar/workshop. (Seminar held in Halifax, Nova Scotia, March 23-26) (Ed: Environment Canada) Environment Canada, Ottawa, 391-410.

1591. Södermark,Björn; Lundgren,Tom (1988): The Bersbo Project - The first full scale attempt to control acid mine drainage in Sweden. Chap. 29. In: Proc. International Conference on Control of Environmental Problems from Metal Mines. (Eds: State Pollution Control Authority; Federation of Norwegian Industries) State Pollution Control Authority, Norway, 17 pages.

1594. Robertson,AMacG; Barton-Bridges,John P; Cowdery,Peter (1988): Control of acid generation for the Cinola Gold Project. Chap. 32. In: Proc. International Conference on Control of Environmental Problems from Metal Mines. (Eds: State Pollution Control Authority; Federation of Norwegian Industries) State Pollution Control Authority, Norway, 11pages.

1613. Skolasinski,David Z; Haile,Jeremy P; Smith,Adrian C (1990): Design objectives and performance of the tailings management system for the Jamestown Mine, California. Chap. 18. In: Mining and mineral processing wastes. (Proc. Western Regional Symposium on Mining and Mineral Processing Wastes, Berkeley, CA, May 30-June 1) (Ed: Doyle,Fiona M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 151-158.

1614. Eivemark,MM; Robinson,KE (1990): A case history of on-going changes in tailings dam design after initial construction. Chap. 19. In: Mining and mineral processing wastes. (Proc. Western Regional Symposium on Mining and Mineral Processing Wastes, Berkeley, CA, May 30-June 1) (Ed: Doyle,Fiona M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 159-168.

1615. Baggs,Charles C; Williams,Steven R; Brooks,Robert E (1990): Rehabilitation and enlargement of tailings impoundment. Chap. 20. In: Mining and mineral processing wastes. (Proc. Western Regional Symposium on Mining and Mineral Processing Wastes, Berkeley, CA, May 30-June 1) (Ed: Doyle,Fiona M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 169-174.
1623. East,Donald R (1990): Performance achievements of drained managed tailings storage facilities. Chap. 28. In: Mining and mineral processing wastes. (Proc. Western Regional Symposium on Mining and Mineral Processing Wastes, Berkeley, CA, May 30-June 1) (Ed: Doyle,Fiona M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 229-233.
1625. Beck,James M; Engelking,James F; Elder,Robert L (1990): Resource recovery: An economic approach to remediation. Chap. 30. In: Mining and mineral processing wastes. (Proc. Western Regional Symposium on Mining and Mineral Processing Wastes, Berkeley, CA, May 30-June 1) (Ed: Doyle,Fiona M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 243-248.
1637. Marshall,Richard C (1991): The costs of environmental mitigation measures: A case study of Noranda's Montanore Project. Chap. 13. In: Environmental Management for the 1990's. (Proc. Symposium on Environmental Management for the 1990's, Denver, CO, February 25-28) (Eds: Lootens,Douglas J; Greenslade,William M; Barker,James M) Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 83-91.
1720. Guo,Weixing; Parizek,Richard R (1994): Field research on thermal anomalies indicating sulfide-oxidation reactions in mine spoil. Chap. 39. In: Environmental geochemistry of sulfide oxidation. (ACS Symposium Series 550; Symposium at 204th National Meeting of the ACS, Washington, DC, Aug. 23-28) (Eds: Alpers,Charles N; Blowes,David W) American Chemical Society, Washington, DC, 645-657.
1748. Norland,Michael R (1993): Reclamation of abandoned tri-state mining district lead-zinc chat tailing. In: Abandoned Mine Land Programs. (Ed: Unknown) Unknown, Unknown, Unknwon. (Presented at 15th Annual Meeting of Association of Abandoned Mine Land Programs, Jackson, WY, Sept. 13-15)
1903. Nordstrom,DK (1991): Chemical modeling of acid mine waters in the Western United States. In: U.S. Geological Survey Toxic Substances Hydorology Program; Proceedings of the technical meeting. (Eds: Mallard,GE; Aronson,DE) U.S. Geological Survey, Tampa, FL, 534-538.
1925. Ralston,Dale R; Trexler,Bryson D Jr; Wai,Chien M; Renison,William T; Rickman,Francis E Jr (1973): Solutions to problems of pollution associated with mining in Northern Idaho. U.S. Bureau of Mines, Washington, D.C.
1928. Wayman,CH (1970): Abatement procedures related to acid mine drainage. In: Proc. Industrial Process Design for Water Pollution Control. Vol. 2. (Ed: Unknown) Unknown, Unknown, 38-44.
2269. Rytuba,James J; Miller,William R (1994): Environmental reclamation proves to be a challenge in the California Coast Ranges. Mineral Resources Newsletter 5(1), 8.
2287. Nawrot,JR; Yaich,SC (1984): The role of weathering and ageing in soils reclamation. In: Proc. Conference on Reclamation of Abandoned Acid Spoils. (Conference held at Missouri Department of Natural Resources, Osage Beach, Missouri) (Ed: Unknown) Cooperative Wildlife Research Laboratory, Sourthern Illinois University, Carbondale, IL, Unknown. (N)
2295. CANMET (Ed.) (1994): 1993 Annual report. Mine Environment Neutral Drainage (MEND) Program, Ottawa. 166 pages.
2363. Caruccio,Frank T (1970): The quantification of reactive pyrite by grain size. In: Symposium on coal mine drainage research. (Ed: Unknown) CMD Research Symposium, Monroeville, PA, 123-131.
2558. Anonymous (1996): 3rd International and the 21st Annual AMIC Environmental Workshop, Newcastle, Australia. October 14-18, 1996.
2574. Orava,DA; Swider,RC (1996): Inhibiting acid mine drainage throughout the mine life cycle. CIM Bulletin 89(999), 52-56.
2783. Anonymous (1997): Environmental plan brings green back to Mt. Lyell. Landline 35, 30.
2794. Walton-Day,Katherine; Kimball,BA; Yager,TJ (1994): The effects of remediation of mine drainage in the Upper Arkansas River near Leadville, CO. 1994 Fall Meeting, 237.
2920. Holm,David (1983): Passive Mine Drainage Treatment: Selcted Case Studies. In: Environmental Engineering. (Eds: Medine,Allen; Anderson,Michael) (1983 National Conference Proceedings of the

ASCE Specialty Conference, Boulder, Colorado, July 6-8, 1983.) American Society of Civil Engineers, New York, New York, 607-617.
3034. Anonymous (1996): 1996 NMLRC Bibliography. Minelands (Fall), 14-24.
3073. Lapakko,Kim; Antonson,David; Jakel,Emmelyn (1998): Mine waste characterization and drainage mitigation: Research summary 1998. Minnesota Department of Natural Resources, Division of Minerals, St. Paul, MN. 50 pages.
3216. BC Ministry of Energy and Mines; MEND Program (Eds.) (1999): Summary Notes 5th Annual BC MEM - MEND 2000 Metal Leaching and ARD Workshop. CANMET, British Columbia.
3353. Unknown (1800): Acid generation potential., .
3477. Hall,Glen JH (1999): "New" Tailings Area Closure: A Case Study. Flaconbridge Ltd., Sudbury Division, Ontario. 13 pages.
3485. Anonymous (Ed.) (1992): Succesful Mine Reclamation: What Works. (May 19-22, 1992, Proceedings from Conference at John Ascuaga's Nugget, Sparks, Nevada), . 458 pages.
3489. Evangelou,VP; Grove,JH; Rawlings,FD (1983): Simulation studies on rates of pyrite oxidation in coal mine sediment ponds. In: Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation. (Eds: Graves,Donald H; DeVore,R William) University of Kentucky, Lexington, Kentucky, 107-111.
3508. Williams,Dave (1994): Legal, philosophical, and regulatory considerations for long term treatment for acid rock drainage. In: Mine Design, Operations, and Closure Conference. (:),, .
3512. Parker,Doug (1994): Acid rock drainage management Crown Butte Mines, Inc. -- New World Project. In: Mine Design, Operations, and Closure Conference. (:),, .
3513. Hamaguchi,RA (1999): Innovative reclamation research at Highland Valley Copper. CIM Bulletin 92(1033), 78-84.
3544. Anonymous (1992): Rehabilitation of mines guidelines for proponents. Ontario Ministry of Northern Development and Mines, Ontario, Canada.
3557. CANMET (Ed.) (1800): Open File Reports. (CANMET) CANMET, Energy, Mines and Resources Canada, Quebec, Canada.
3558. Robertson,AMacG; Barton-Bridges,JP (1988): Acid mine drainage in British Columbia: Analysis of results of questionnaire from Acid Mine Drainage Task Force. (Reoprt 66001-1) Steffen, Robertson, and Kirsten, Inc, Vancouver, Canada. 60 plus appendices pages.
3561. Wood,Nancy; Shannon,Robert; Owsiacki,Leo; Walters,Martin (Eds.) (1993): Summary report: 1992-1993. Ministry of Northern Development and Mines, Ontario.
3566. Steffan Robertson and Kirsten Inc.; Norecol Environmental Consultants Ltd.; Gormely Process Engineering (Eds.) (1989): Draft Acid Rock Drainage Technical Guide. Vol. I and II. Steffen Robertson Kirsten, Inc, Vancouver, Canada.
3567. Geological Association of Canada; Mineralogical Association of Canada (Eds.) (1990): Vancouver '90. Vol. 15. Geological Association of Canada, Mineralogical Association of Canada, .
3576. Bernard,DW (1983): Arsenic leachate from an abandones smelter, Deloro, Ontario, Canada. In: Australian Water Resources Concil Conference Series. Vol. 8. (Sydney, Australia, December 5-9, 1983) (:) (International Conference on Groundwater and Man, Volume 2, Groundwater and the Environment.),, 29-41.
3587. Kuit,WJ (1980): Mine and tailings effluent treatment at the Kimberly, BC operations at Cominco Ltd. CIM Bulletin (December), 105-112.
3601. MEND Program (Ed.) (1993): 1992 Annual Report. MEND, Ottawa, Ontario. 146 pages.
3602. Yanful,Ernest K; Payant,Serge C (1992): Evaluation of techniques for preventing acidic rock drainage. (First Milestone Research Report.) Noranda Technology Centre, Quebec, Canada. 82 pages.
Pitt94 Clarke, W.P. et al. (1994) AMD prediction and control methods- An update from Australian case studies. V2.
Pitt94 Meek, F.A. Jr. (1994) Evaluation of acid prevention techniques used in surface mining.
Pitt94 Williams, R.D. (1994) Montana reclamation: A progress report on the Golden Sunlight Mine. What's working best. V2.
Sud95 Chen, L.; Huang, X. (1995) Environmental problems and their treatments in Chinese coal mines.

Sud95 Feasby, D.G.; Tremblay, G.A. (1995) New technologies to reduce environmental liability from acid generating mine wastes.
Sud95 Nordstrom, D.K.; Alpers, C.N. (1995) Remedial investigations, decisions, and geochemical consequences at Iron Mountain Mine, CA.
Sud95 Payne, R.A. (1995) Decommissioning of Elliot Lake mining properties.
Sud95 Smith, F.E. (1995) The treatment of metalliferous industrial effluents in Japan.
Van97 Delaney, T. et al. (1997) Applications of method for delaying the onset of acidic drainage. V2.
Van97 Firth, I.C.; van der Linden, J. (1997) ARD control at P.T. Kelian Equatorial Mining. V3.
Van97 Gustafsson, H. (1997) A summary of the Swedish AMD experience. V4.
Van97 Hope, G. et al. (1997) Waste rock management planning for the Kudz Ze Kayah project, Yukon Territory: 2. Waste management strategy. V1.
Van97 Jakubick, A.T. et al. (1997) The WISMUT waste rock pile remediation program of the Ronneburg Mining District, Germany. V3.
Van97 Kistinger, S. (1997) Reclamation strategy at the Ronneburg Uranium Mining site before flooding the mine. V3.
Van97 Perry, E.F. et al. (1997) Effects of acid material handling and disposal on coal mine drainage quality. V3.
Van97 Stuparyk, R.A. et al. (1997) Methods of diverting surface runoff water from acid mine drainage at INCO's Copper Cliff tailings area. V4.
Van97 Thomson, D.G. et al. (1997) Mark Creek improvement project control of ARD in the lower mine yard, Kimberley, British Columbia. V1.
Sud99 Aiken, S.R. et al. (1999) Nickel Rim site closure studies site investigations and long-term closure options. V1.
Sud99 Alvarez, S.M.; Ridolfi, B.A. (1999) Moon Creek reclamation project- creative clanup solutions for a historic mine site. V3.
Sud99 Berg, G.; Arthur, B. (1999) Proposed mine water treatment in Wisconsin. V2.
Sud99 Burns, R.C. et al. (1999) A case study of the rehabilitation of sulfide tailings at the Coldstram Mine, tailings management area No. 2. V1.
Sud99 Ketellapper, V.L.; Christiansen, J.W. (1999) Effectiveness of site stabilization activites at the Summitville mine to reduce acid rock drainage. V1.
Sud99 Martin, J.C. et al. (1999) Acid rock drainage assessment programs at the Kumtor gold mine, Kyrgyzstan, and the Bogoso gold mine, Ghana. V1.
Sud99 Peters, T.H. (1999) A half century of experience in land reclamation. V3.

APPENDIX 2

Annotated Bibliography of References
Physical Containment of Reactive Mine Wastes
Dry Cover Systems

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A2.1. General

THE EVALUATION OF EVAPORATIVE FLUXES FROM SOIL SURFACES FOR THE DESIGN OF DRY COVERS AND THE ABATEMENT OF ACID DRAINAGE.
Wilson, G.W., Barbour, S.L., Fredlund, D.G.
44th Annual Canadian Geotechnical Conf. Oct. 1991, Calgary, Canada.
#1297

Summary: Extreme difficulties are encountered when attempting to predict evaporation from unsaturated soil surfaces. The traditional methods of evaluating evaporation from a theoretical basis provide only an estimate of potential evaporation. These methods assume the evaporating surface is fully saturated. This approach is appropriate for predicting evaporative rates from ponds and water reservoirs. However, actual rates of evaporation from unsaturated soil surfaces are often much less than the potential rate of evaporation. A mechanistic approach for predicting evaporation from unsaturated surfaces suitable for applications in geotechnical engineering is not available in the literature. Several empirical methods for estimating evaporation from unsaturated soil surfaces are available; however, the reliability and accuracy of these methods are questionable.

This paper presents a theoretical model for predicting the rate of evaporation from unsaturated soil surfaces. The theory is founded on the well-known principles of Darcy's Law and Fick's Law to describe the flow of liquid water and water vapor in the soil below the soil-atmosphere boundary. Dalton's Law and a modified Penman formulation are used to describe water vapor transfer above the soil-atmosphere boundary.

Results: Laboratory column evaporation test results show that evaporative fluxes from a soil surface are controlled by the soil suction at tank below the soil-atmosphere boundary. Furthermore, soil evaporative fluxes are also strongly dependent on ground water conditions and the flow properties of the soil. The theoretical model for soil evaporation was used to simulate the evaporative fluxes measured from the soil columns during the laboratory evaporation test. The theoretical model provided good agreement with the evaporative fluxes measured in the lab over a six week period.

SOILCOVER, A NEW COMPUTER MODEL TO AID IN THE DESIGN OF SOIL COVER SYSTEMS FOR ACID GENERATING WASTE ROCK AND TAILINGS.
O'Kane, M.
(1993)
#1412

THE DIFFUSION OF IONS IN UNCONSOLIDATED SEDIMENTS.
Manheim, F.T.
Earth and Planetary Sci Lett., 9, 1970, pg 307-9.
#2663

Summary: Diffusion in unconsolidated sediments generally proceeds at rates ranging from half to one twentieth of those applying to diffusion of ions and molecules in free solution. Diffusion rates are predictable with respect to porosity and path tortuosity in host sediments, and can be conveniently measured by determinations of electrical resistivity on bulk sediment samples. Net ion flux is further influenced by reactions of diffusing species with enclosing sediments,

but such influences should not be confused with or lumped with diffusion processes.

LABORATORY DETERMINATION OF DIFFUSION AND DISTRIBUTION COEFFICIENTS OF CONTAMINANTS USING UNDISTURBED CLAYEY SOIL.
Rowe, R.K., Caers, C.J., Barone, F.
#2664

Summary: The objective was to describe a technique for determining some of the key parameters for saturated natural clay liners by means of a modified column test. The application of the technique will then be demonstrated with regard to the migration of various salt solutions through undisturbed samples of clayey till from Sarnia, ON. A simple theoretical mode is used to analyze this case and showed that this phenomenon can be used to deduce both the diffusion coefficient and the distribution/partitioning coefficient from a single test.

LABORATORY DIFFUSION TESTING FOR WASTE DISPOSAL-A REVIEW.
Shackelford, C.D.
J. Contaminant Hydrology, 7, 1991, pg 177-217.
#2665

Summary: This paper reviews the state-of-the-art for the measurement in the laboratory of diffusion coefficients of chemical waste constituents in fine-grained soils. The review presents experimental and analytical methods for determining liquid-phase diffusion coefficients which can be used in practice for the design and evaluation of waste containment barriers.

THE DESIGN AND IMPLEMENTATION OF THE FIELD TEST PLOTS AT BHP IRON ORE, MT WHALEBACK-A COVER SYSTEM FOR AN ARID CLIMATE.
O'Kane, M., Perterfield, D., Endersby, M., Haug, M.D.
SME Preprint 98-70
#2863

Summary: BHP Iron Ore initiated research programs in January of 1995 to develop long term plans for decommissioning of the waste rock material at their Mt. Whaleback operation. More than 2 billion tons of waste rock were deposited during the past 30 years. The primary research program includes the development of technology for the long term performance of the waste rock dumps with respect to vegetation, slope stability, surface runoff, erosion, and water infiltration. This paper focuses on the design and implementation of a cover system to prevent water infiltration to the underlying waste rock. A laboratory program and the soil-atmosphere modeling completed to design the horizontal field test plots are described. The construction of the horizontal surface field test plots are discussed together with the field instruments installed to monitor performance. The key components of the instrumentation program are the design and installation of large scale field lysimeters to measure the unsaturated flow of moisture into the waste rock from the base of the cover layer.

The cover system is designed to maximize infiltration during wet periods for subsequent evapotranspiration while minimizing surface runoff. The result is a near zero net infiltration to the underlying waste material. A key feature of the design is the use of pit run waste material as the cover material. Monitoring is in progress and will continue for at least two annual wet/dry cycles.

MONITORING SYSTEM FOR HYDROLOGIC EVALUATION OF LANDFILL COVERS.
Benson, C.H., Bosscher, P.J., Lane, D.T., Pliska, R.J.
Geotechnical Testing J. (1994)
#2864

Summary: This paper was the first in a series regarding three test sections constructed to evaluate the field-scale hydraulic behavior of earthen final covers at two municipal landfills. This was a preliminary report, focusing mainly on the methods and instrumentation selection and justification.

MODELING THE PERFORMANCE OF ENGINEERED SOIL COVERS FOR ACID GENERATING MINE WASTE.
Swanson, D.A., Barbour, S.L., Wilson, G.W., O'Kane, M.
Sud95, V2, pg 861.

Summary: MEND's soil-atmosphere model, SoilCover, was used to model the field responses of an in-place cover system using compacted glacial till over a waste rock pile. This was intended to be a field response modeling effort rather than predictive. This was also intended to provide a physically-based methodology for engineered soil covers.

Model: The model provided a daily quantification of the surface water balance coupled to the soil profile. Parameters calculated were potential evaporation, soil water characteristic curve, hydraulic conductivity function, thermal conductivity versus gravimetric water content, specific heat versus gravimetric water content, oxygen diffusion coefficient versus degree of saturation, and oxygen flux.

EVAPORATIVE LOSSES, SALT MIGRATION AND MINERALOGICAL CHANGES IN DRY COVERS OVER OXIDIZED TAILINGS.
Elliott, L.C.M., Davidson, J.G., Liangxue, L.,Strogran, S.W.
Van97, V3, 1211

Summary: The upward migration of salts from oxidized tailings to the surface of dry covers has been identified as a concern for the long term viability of vegetative covers and metal loading to surface waters. Large bench scale column tests were conducted to determine the susceptibility of several organic and inorganic cover materials to salt migration. The materials tested included desulfurized tailings, desulfurized tailings with a capillary barrier, lime-stabilized sewage sludge, peat, mature compost and a control cell containing only oxidized tailings.

Theory: The surface evaporation rate, electrical conductivity and degree of salt migration each exhibited an inverse correlation with cover depth. Te increased depth of the cover material was associated with decreased evaporative losses and lower electrical conductivity. All cover materials reported elevated surface electrical conductivity as the drought period extended in duration. Cracking, due to desiccation and shrinkage, augmented evaporative losses by increasing surface exposure. A direct correlation was noted between evaporation rate and air entry value, while an inverse relationship was noted between evaporation rate and D_{10} particle size. The evaporation rate in the control cells decreased with time to zero mm per day.

Results: The diminishing evaporation rate was attributed directly to the formation of a salt 'crust' at the surface of the tailings and/or cover material. Mineral salts including starkeyite and

hexahidrite, rozenite, gypsum and $NaSO_4$ occurred on the surface and within upper regions of the shrinkage cracks of the tailings and various cover materials. Delicate to massive encrustations and intricate filiform arrays of crystals exhibited white, yellow, brown and green coloration; the development of the salt 'crust' may have contributed to local in-situ brecciation of the surface material. The dominant mineral salt was related directly to the mineral chemistry of the tailings independent of the type or depth of cover material.

DRY-SITE VERSUS WET-SITE COVER DESIGN.
Swanson, D.A., Barbour, S.L., Wilson, G.W.
Van97, V4, pg 1595
Summary: Wet covers over wet sites, dry covers over dry sites.

A DISCUSSION OF SEISMIC DESIGN CONSIDERATIONS FOR SOIL COVERS ON TAILINGS
Ritchie, D.G.
Sud99, V1, pg 49

Abstract: Soil covers are constructed on sulfide-bearing tailings to control the ingress of oxygen and/or water, thus controlling the rate of acid production and contaminant migration. Following seismic events, cracked or otherwise damaged covers may fail to function as designed and could allow oxidation to proceed at an increased rate. Significant costs are associated with the design and construction of soil covers; similarly, efforts to restore damaged covers could also become costly. Therefore, it is prudent to identify possible failure mechanisms and quantify the potential effects at the design stage, when measures can implemented relatively easily to provide additional safety against seismic damage.

OXYGEN TRANSPORT THROUGH MULTILAYER COMPOSITE CAPS OVER MINE WASTE
Kim, H., Benson, C.H.
Sud99, V1, pg 183

Abstract : A finite element model was used in this study to predict gas-phase diffusive transport of oxygen through multilayer composite caps overlying Mine wastes. Two sets of diffusion coefficients were used. One set was estimated using the Reardon-Moddle equation. The other set was obtained from previous studies that used soils having similar texture as those used in multilayer caps. Profiles of oxygen concentration show that the composite barrier layer (i.e. a geomembrane overlying ad GCL) in multilayer composite caps is the primary impediment to diffusive transport. Concentrations above and below the composite barrier differ by as much as 10 orders of magnitude. Also, concentrations in layers directly beneath the composite barrier layer as much as 24 orders of magnitude larger when the cap does not have a composite barrier. Oxygen fluxes for multilayer composite caps were found to be very low (<10 moles/m^2 yr), and were ten times lower than those for similar caps without a composite barrier layer. Oxygen fluxes were also sensitive to the method used to estimate the diffusion coefficient. Fluxes predicted using diffusion coefficients estimated with the Reardon-Moddle equation were typically lower than fluxes predicted using the "best-estimate" diffusion coefficients.

EFFECTS OF SPATIAL VARIABILITY ON OXYGEN TRANSPORT IN SULFIDIC MINE WASTE DEPOSITS

Werner, K., Berglund, S.
Sud99, V1, pg 243

Abstract: Substantial reduction in the flux of oxygen in sulfidic Mine waste deposits could potentially be achieved by covering the waste with an oxygen diffusion barrier. This study concerns Mine waste deposits covered with a dry cover. Expressions for oxygen diffusion into covered Mine waste deposits are derived, where spatial variability in the diffusion properties of the cover and the waste materials is taken into account, and a stochastic approach to analyze the oxygen flux is outlined. The effects of heterogeneity in the cover and waste materials are investigated by assuming that the water-retention parameters of these materials are subjected to sensitivity analysis. The results for the diffusive flux are compared with the rate of advective oxygen transport with infiltrating water. The study indicates that for covered Mine waste deposits the diffusive flux of oxygen is sensitive to heterogeneity in the cover material, which therefore should be subject to detailed analysis, but not to the reaction rate and heterogeneity in the physical properties within the waste deposit. Depending on the quality of the cover, advection with infiltrating water may be the dominant oxygen transport mechanism.

MEASUREMENT OF OXYGEN DIFFUSION COEFFICIENT IN COVERS ON WASTE ROCK AT MARTHA MINE, NEW ZEALAND
Garvie, A.M., Brodie, K.M.
Sud99, V1, pg 253

Abstract: Martha Mine, a Normandy Mining Ltd Mine, is located in Waihi, New Zealand, where the average annual rainfall is 2.1 m and the average ambient temperature is about 14 °C. A cover on the sulfidic waste rock dump produced by the present mining operation has been designed in part to control the supply of oxygen into the waste. The cover consists of three layers. The top layer is topsoil and is approximately 0.1 m thick. The second layer is a plant growth horizon at least 0.5 m thick and serves to prevent erosion of the third layer. The third layer is at least 1.5 m thick and has a low saturated hydraulic conductivity of about 1×10^{-8} m/s which is around one twentieth of that of the second layer. Both the second and the third layers have been constructed of non acid generating waste.

Between February 1995 and February 1998 a tracer technique was used to determine the oxygen diffusion coefficient in the second and third layers of the cover after various rainfall regimes. Diffusion coefficients were determined by injecting a tracer gas into the cover and measuring the tracer concentration at other positions within the cover. The technique has been shown to be able to measure diffusion coefficients greater than 5×10^{-9} m^2/s. Diffusion coefficients in the second layer were found to be in the range $(0.2 \text{ to } 9.3) \times 10^{-7}$ m^2/s, while the oxygen diffusion coefficient of the third layer was less than $5 \times 10^{-9} m^2/s$.

PRACTICAL CONSIDERATIONS FOR COVERING SULFIDIC TAILINGS DEPOSITS SITUATED ABOVE THE GROUND WATER TABLE
DeVos, K.J., Ritchie, D.G., Bocking, K.A.
Sud99, V1, pg 291

Abstract: Tailings located above the water table will oxidize to some degree. In many cases remediation of these types of deposits will involve installation of a cover of some type. Cover design can range from an oxygen barrier cover to limit acid generation, to a water-shedding cover to limit groundwater impacts, or an aesthetic cover to protect from surface contact and erosion. Practical consideration of many factors will assist in identification of the

most appropriate remediation option or cover design for these types of tailings.

This paper identifies practical considerations in defining and determining the significance of various aspects of cover selection and design. Among the most important components will be: technical considerations (geochemistry, hydrogeology, engineering design); the regulatory environment; and economic considerations. An assessment of the overall system and a thorough understanding of the tailings and site conditions are all necessary components that will lead to sound remediation and cover strategies. A practical approach which identifies and assesses these factors from all perspectives will lead to solutions that will incorporate the best economic strategies to limit environmental impacts to acceptable levels.

A REVIEW OF DRY COVER PLACEMENT ON EXTREMELY WEAK, COMPRESSIBLE TAILINGS
Wels, C.; Robertson, A.M.; Jakubick, A.T.
Sud99, V2, pg 791

Abstract: Increasingly, the successful reclamation of tailings impoundments involves placing permanent dry or wet covers over the tailings to provide isolation and control of radiological, oxidation and/or leaching effects. This paper reviews key issues related to the placement of dry (soil) covers on extremely weak, compressible fine tailings. The design and construction of soil covers on such tailings often presents a formidable challenge to the geotechnical as well as the environmental engineer due to the low shear strength, poor trafficability, and high settlement of under consolidated tailings at the time of reclamation. The geotechnical issues to be considered include: (i) consolidation of near-surface tailings to achieve strength gains, improve trafficability, and allow safe placement of initial cover layer; (ii) stability of tailings slopes during dewatering of tailings ponds and/or cover placement, and (iii) long-term settlement of tailings and its impact on cover integrity and final surface shaping. The environmental issues to be considered include (i) management of contaminated (free) pond water; (ii) management of contaminated pore water expelled during tailings consolidation; and (iii) management of (uncontaminated) surface water on top of the cover. This paper summarizes recent experiences gained in a large uranium tailings reclamation project. It is concluded that a careful consideration of both geotechnical and environmental issues during the planning stages greatly reduces the costs and environmental risks associated with fine tailings reclamation.

A2.2. Capillary Barriers

CAPILLARY BARRIERS IN COVERS FOR MINE TAILING DUMPS.
Rasmuson, A., Eriksson, J.C.
Nat. Swedish Environ. Protection Board Report 3307, 1987.
#912

Summary: The possibility of using capillary barriers, containing fine and coarse soil layers, to reduce water infiltration into Mine tailings is explored. A detailed account of the hydrological and physicochemical basis for the phenomenon is given. It is established that the capillary barrier will, in practice only function if the fine layer remains somewhat unsaturated. To avoid ponding the hydraulic conductivity of the fine material must, in the present context, be larger than 10^{-4} m/s. A hydraulic conductivity of this magnitude is in conflict with the main purpose of the fine material to reduce inward diffusional transport of oxygen.

Theory: Unsaturated flow theory and capillarity in a single porous layer and mixed porous layers explained

Literature Review of Previous Investigations

REDUCTION OF ACID GENERATION IN MINE TAILINGS THROUGH THE USE OF MOISTURE-RETAINING COVER LAYERS AS OXYGEN BARRIERS.
Nicholson, R.V., Gillham, R.W., Cherry, J.A., Reardon, E.J.
Can. Geotech. J. 26, 1-8 (1989)
#1131

Summary: The availability of gaseous oxygen and the rate of diffusion of oxygen through the open pore spaces in the upper zone of the tailings are the critical factors controlling the rate of acid generation. Acid generation can be reduced by applying a fine-grained, nonreactive cover layer to the tailings surface. The key process involves moisture retention in the fine layer when infiltration exceeds evapotranspiration. The application of such a cover layer can theoretically reduce oxygen diffusion coefficients and rates of acid generation by up to four orders of magnitude. This can represent a substantial difference in the potential treatment costs of tailings seepage. Simplified calculations based on Fick's law can be applied to preliminary laboratory measurements of diffusion characteristics of potential cover materials to evaluate their effectiveness in decreasing acidification. These concepts and methods provide an initial evaluation before field-scale testing of cover performance.

Oxygen transport in porous media:

Hydraulic principles:

Oxygen diffusion thru a cover layer:

SATURATED TAILINGS COVERS ABOVE THE WATER TABLE: THE PHYSICS AND CRITERIA FOR DESIGN.
Nicholson, R.V., Akindunni, F.F., Sydor, R.C., Gillham, R.W.
Montreal 1991, #1395.

Summary: This paper examined the physical principles that governed the control of moisture in porous media, and presented evidence to show how selective layering maintained near saturated conditions in covers regardless of the depth to the water table. A simple1-D vertical drainage scenario was developed to test the importance of transient behavior in layered media. In the first example, 1 m of structured silt overlies a sandy medium (representative of sulfide tailings). The second example includes the unstructured silt as a the cover layer and illustrates the concept of a poorly drained fine-grained medium overlying a coarser one. Laboratory columns were designed to verify the concepts involved in the drainage of layered media.

Introduction: Covers moisture controls, drainage curves in homogenous media, hydraulic conductivity and moisture content in general and in layered media.

Modeling transient drainage:
Physical scenario described along with the material properties. Predicted moisture content profiles and saturation as a function of pressure head in a layered system

Laboratory Experiments:

Describes columns and instrumentation (tensiometers connected to pressure transducers and TDR)

Describes material properties

Results: The results suggest that moisture retention in a cover layer is enhanced by selective matching of material properties (pressure head approaching residual saturation and AEV) with the underlying medium.

ENGINEERED SOIL COVERS FOR REACTIVE TAILINGS MANAGEMENT: THEORETICAL CONCEPTS AND LABORATORY DEVELOPMENT.
Yanful, E.K.
Montreal 1991, #1396

Summary: This paper presents work undertaken by Noranda Technology Centre and U of Waterloo to develop laboratory methodology and apparatus for evaluating the effectiveness of engineered soil covers for sulfide tailings. Discusses theory of hydraulic properties and flux calculations. Local tills were used as the moisture retaining layer. Oxygen transport was mainly by molecular diffusion through gas-filled pores. Saturated soil covers decreased oxygen diffusion coefficients by orders of magnitude.

Theoretical Concepts:

Covers oxygen diffusion using Fick's first and second laws and hydraulic properties of saturated soil covers.

Laboratory: Soils from Heath Steele and Faro mines: measured index properties, geotechnical behavior, hydraulic behavior, and oxygen diffusion.

DESIGN, INSTRUMENTATION, AND CONSTRUCTION OF ENGINEERED SOIL COVERS FOR REACTIVE TAILINGS MANAGEMENT.
Yanful, E.K., St-Arnaud, L.C.
Montreal, 1991, pg 487, #1397

Summary: Describes the design and installation of two 20 x 20 m test plots of engineered composite soil covers on the Waite Amulet tailings. Soil covers were a compacted saturated clay layer sandwiched between gravelly sand and medium sand layers. Two control (HDPE sheet and uncovered) plots were also monitored.

Instrumentation: Gaseous oxygen, moisture content, suction, temperature and pore water quality were monitored.

Results: Preliminary results (2 months) indicate that moisture contents had not changed, attenuation of oxygen and elimination of infiltration. Temp increased with depth And lysimeters underneath the covered test plots were dry.

MATHEMATICAL MODELING OF WATER AND OXYGEN TRANSPORT IN LAYERED SOIL COVERS FOR DEPOSITS OF PYRITIC MINE TAILINGS.
Collin, M., Rasmuson, A.

Acid Mine Drainage: Designing for Closure (1990) pg 311
#1504
Summary: Identical to #1590!

MATHEMATICAL MODELING OF WATER AND OXYGEN TRANSPORT IN LAYERED SOIL COVERS FOR DEPOSITS OF PYRITIC MINE TAILINGS.
Rasmuson, A, Collin, M.
Proc. Internat'l Conf on Control of Environmental Problems from Metal Mines (1988)
#1590

Summary: The purpose was to investigate whether covering is an efficient method to reduce (AMD) and to give a theoretical ground for determining the efficiency of soil covers of different designs.

Mechanism: O_2 diffusion through a cover dependent on water content. Sulfide oxidation is dependent on the rate of oxygen transport through the cover.

Calculations: The model follows the following steps: 1) water transport based on climate data, geometry, K and Ψ, which results in water flow rates and moisture content profiles. Moisture content profiles and porosities lead to 2) diffusivity calculations (D) used to calculate 3) oxygen transport resulting in an oxygen profile and oxidation rate.

Results: Very low oxygen transport rates were obtained for covers containing a fine-grained layer with high moisture content (capillary barrier).

FIELD-SCALE COMPARISON OF CAPILLARY AND RESISTIVE LANDFILL COVERS IN AN ARID CLIMATE.
Khire, M.V., Benson, C.H., Bosscher, P.J., Pliska, R.J.
#2865

Summary: This paper presents hydrologic data used to evaluate resistive and capillary barriers being considered for use as a landfill cover in an arid region. Two test sections representing final covers have been constructed at a municipal solid waste landfill in East Wenatchee, WA. The traditional resistive barrier is constructed with a compacted silty clay barrier 600 mm thick and a silty clay surface layer 150 mm thick. The capillary barrier has a sand layer 750 mm thick overlain by a surface layer of silt 150 mm thick. Hydrologic and climatic data including precipitation, air temperature, solar radiation, relative humidity, wind speed, and wind direction have been collected since Nov, 1992. Percolation is collected using a lysimeters, overland flow is collected via diversion berms. TDR is used to measure soil water content.

Results: The capillary barrier has been more effective than the resistive barrier in restricting percolation. The data also show that the water content of both barriers increases dramatically during winter because of precipitation and then decreases during spring, summer, and fall as a consequence of evapotranspiration. The data also reveal that the capillary barrier effect is realized at large scale. During the wetting period the upper fine grained silt becomes nearly saturated, but the water content of the underlying sand layer increases only moderately, thus minimizing percolation.

REDUCTION OF ACID GENERATION IN MINE TAILINGS THROUGH THE USE OF MOISTURE-RETAINING COVER LAYERS AS OXYGEN BARRIERS: DISCUSSION.

Barbour, S.L.
Can. Geotech. J. 27, (1990) 398-401

Summary: Comments that the design criteria for layered covers described by Nicholson may be somewhat limited in scope. In some cases they may be overly severe and uneconomical to implement. However, if the assumption of a drip surface is utilized, the design criteria may not be on the conservative side. Illustrated that the moisture contents within the cover are not solely a function of the moisture retention characteristics of the material, but are also influenced by the water flux that develops through the cover as a result of climatic factors. The pressure profiles and the resulting moisture contents within the cover may deviate significantly from those postulated on the basis of static conditions. A simple design approach is used to illustrate the pressure head profiles that will develop in a silt cover under steady state conditions. These pressure heads can then be related to moisture contents.

NUMERICAL SIMULATIONS TO INVESTIGATE MOISTURE-RETENTION CHARACTERISTICS IN THE DESIGN OF OXYGEN-LIMITING COVERS FOR REACTIVE MINE TAILINGS.
Akindunni, F.F., Gillham, R.W., Nicholson, R.V.
Can. Geotech. J., 28, (1991) 446-51

Summary: Influx of atmospheric oxygen into a material at depth can theoretically be minimized by maintaining a protective cover layer at high moisture content. Such oxygen limiting covers are generally of finer texture than the material being protected. A numerical model was used to investigate the importance of moisture retention characteristics in the transient drainage of such two layer systems. The results show that the effectiveness of a material as a moisture retaining cover is dependent on the magnitude of its air entry value. The thickness of the cover maintained at full saturation after prolonged drainage also depends on the pressure head at which the underlying material approaches residual saturation.

DESIGN OF A COMPOSITE SOIL COVER FOR AN EXPERIMENTAL WASTE ROCK PILE NEAR NEWCASTLE, NEW BRUNSWICK, CANADA.
Yanful, E.K., Bell, A.V., Woyshner, M.R.
Can. Geotech. J., 30, (1993) 578-87.

Summary: **Pile 7/12** was relocated and reconstructed on an impermeable synthetic membrane. It contains about 14000 t of Mine waste rock and has been producing acidic seepage (pH = 2.1-2.8, Fe = 3.5-13.5 g/L, $SO_4^{\cdot}$ = 12.7-43.4 g/L). Composite cover designed as 30cm sand base, 60 cm saturated impermeable cover, 30 cm granular layer to minimize oxygen diffusion and to attain a low hydraulic conductivity to reduce infiltration into the pile. Modeling results used in the design are discussed along with the geotechnical specifications (table 3) for the cover materials.

CONSTRUCTION AND MONITORING OF A COMPOSITE SOIL COVER ON AN EXPERIMENTAL WASTE-ROCK PILE NEAR NEWCASTLE, NEW BRUNSWICK, CANADA.
Yanful, E.K., Riley, M.D., Woyshner, M.R., Duncan, J.
Can. Geotech. J., 30, (1993) 588-99

Summary: A 130 cm thick soil cover (30 cm sand base, 60 cm compacted till, 30 cm granular, 10 cm gravel for erosion protection) was constructed on pile 7/12 at Heath Steele. Till was

compacted on the sand base in 20 cm lifts. Water saturation of at least 95% due to this compaction. Decreased oxygen in the pile from 20% to 3%. Volumetric water contents averaged 32% in the till. Seepage quality had not changed after installation. Table 1 provides construction specifications for the cover. Table 2 provides a description of instrumentation installed in the cover and waste rock pile.

EVALUATION OF SULFIDE OXIDATION RATES: A LABORATORY STUDY COMPARING OXYGEN FLUXES AND RANGES OF OXIDATION PRODUCT RELEASE.
Elberling, B., Nicholson, R.V., Reardon, E.J., Tibble, P.
Can. Geotech. J., 31, (1994) 375-83

Summary: A series of column experiments were conducted to evaluate three methods to determine sulfide oxidation rates in Mine tailings. Measurements were made of (i) the flux of oxygen across the surface of the tailings, (ii) the oxygen consumption rates at the tailings surface, and (iii) the total sulfate produced in the pore water over time. Two columns were prepared with a mixture of quartz sand and pyrrhotite and overlain with varying thicknesses and grain sizes of a nonreactive layer. The impact of nonreactive layers with varying water-table depths on the overall oxidation rate was also evaluated. Modeling was applied to verify the importance of diffusion and kinetic control of the different column configurations. The results indicate that the overall rate of oxidation is reduced when fine-grain layers are applied. This is due to the high water saturation conditions generated by the fine material regardless of the depth to the water table. The consistency and precision of the methods used to measure relative oxidation rates were noted and a new practical field mapping tool is recommended. The new method provides rapid measurements of relative oxidation rates that can be applied to existing tailings rehabilitation with soil-type covers to show spatial and temporal trends.

Methods: Describes analytical techniques (CO_3 and S^{2-} contents, XRD, oxygen sensors, TDR), columns (Plexiglas 1 m x 0.11 m), instrumentation (gas sensors, TDR), and modeling of a simplified, first order kinetics oxidation process

OXYGEN DIFFUSION THROUGH SOIL COVERS ON SULFIDIC MINE TAILINGS.
Yanful, E.K.
J. Geotech. Eng., 119, 8, 1993, 1207-28.

Summary: The objective of the paper is to present laboratory and field measurements of gaseous oxygen diffusion into soil covers (Noranda, MEND). Column experiments were conducted to: 1. determine oxygen diffusion coefficients of a till at various degrees of water saturation; 2. evaluate performance of a 3-layer (varved clay and sandy soils) tailings cover system. Also, compares lab and field oxygen profiles observed in covered and uncovered tailings.

Results: Effective diffusion coefficients ranged from 8.3×10^{-8} m^2/s to 6.2×10^{-6} m^2/s at 3 and 90% degrees of water saturation, respectively. Theoretical fluxes indicate a 97% reduction of the max. acid flux by the 3-layer (column) cover system. In comparison to field oxygen profiles indicate a 99% effectiveness in the exclusion of oxygen. D_e was 3.9-9.9 x 19^{-9} m^2/s in lab and field, respectively. Both lab and field confirm that min. clay layer thickness=30cm.

FIELD EVALUATION OF ENGINEERED SOILCOVERS ON TAILINGS- WAITE AMULET.
Anonymous, 1994

Summary: Results of the laboratory, field and modeling studies indicated that the oxygen flux is reduced by 91 to 99% by the soil cover. Monitoring of acid fluxes over time show that the rate of acid production decreases with time.

MITIGATION OF ACID MINE DRAINAGE BY THE POROUS ENVELOPE EFFECT.
St-Arnaud, L.C., Aube, B.C., Wiseman, M.E., Aiken, S.R.
Pitt94, V2, pg 87.

Summary: The objective was to analyze the chemical and physical hydrogeology of the Fault Lake tailings site, to delineate areas affected by AMD generated from the tailings, and to verify the presence of the porous envelope effect within the tailings mass. This paper is more about determining and modeling a porous envelope effect (capillary barrier?) than about using multilayered covers of any type.

EVALUATION OF A COMPOSITE SOIL COVER TO CONTROL ACID WASTE ROCK PILE DRAINAGE.
Bell, A.V., Riley, M.D., Yanful, E.K.
Pitt94, V2, pg 113.

Summary: This paper deals with the design, installation, and monitoring of a composite soil cover installed on a waste rock pile at Heath Steele Mine, New Brunswick.

Methods: The covers 0.25 ha in plan, and has a maximum depth of 5 m (maximum slope of 3:1). The waste rock pile was underlain by a sand layer and an impermeable membrane. The cover consisted of a 60 cm of saturated, compacted glacial till sandwiched between 30 cm sand, and 10 cm surface coarse granular material (58% sand, 40% gravel). Soil suction, soil temperature, water content, and oxygen concentration were measured.

Results: Reported oxygen concentrations dropped from an initial range of 7.3 - 20.8 % to 8.2 - 14.5% immediately after the cover was in place to 0.2 - 0.7 % after five years. There has been no noticeable change in the moisture content of the glacial till layer. They claim that the drainage quality is improving, however, I find the improvement to be minimal.

COLUMN TESTS INVESTIGATION OF MILLING WASTES PROPERTIES USED TO BUILD COVER SYSTEMS.
Aachib, M., Aubertin, M., Chapuis, R.P.
Pitt94, V2, pg 128.

Summary: The authors briefly review the basic principles behind the design of mlc systems to control acid production. Then some of the main components of an ongoing lab investigation are presented. The emphasis is placed upon column tests procedures used to evaluate various cover configurations. Some analytical and numerical solutions to specific problems related to cover design are finally given.

Capillary Barrier Concept:

1) Discusses capillary characteristics including the Ψ-Θ relationship, and the influences on K and D_e (provides references for measuring curves). Good description of characteristics and the capillary layer thickness. (2) Discusses unsaturated flow wrt Darcy's law.

Experimental:
1) Consolidation behavior-standard odometer tests
2) Hydraulic conductivity-constant head and falling head tests in odometer cells and in rigid-wall permeameters
3) Capillary characteristic curves
4) Transport of oxygen (diffusion)
5) 1-4 used in numerical model, calibrated and validated by column tests
6) Drainage column tests- to estimate water conditions existing in the cover-instrumented with tensiometers (suction) and TDR (water content)
7) Control column tests-evaluate cover performance-TDR, thermocouples, analyze effluent

Preliminary Calculations:
Used Fick's law to consider oxygen diffusion through a cover, and therefore, the efficiency of the cover layer, also oxygen flux for the cover system.

Conclusions: A degree of saturation of 90% in a porous material produced a layer that has about the same D_e as water. Tailings present some very interesting properties (relatively low K, high water retention, capacity to reduce O_s flow) as a constitutive material in a multilayered system.

FIELD AND LABORATORY PERFORMANCE OF ENGINEERED COVERS ON THE WAITE AMULET TAILINGS.
Yanful, E.K., Aube, B.C., Woyshner, M., St-Arnaud, L.C.
Pitt94, V2, pg 138.

Summary: The Waite Amulet Covers Project consisted of a combined field and laboratory study. The field study covered tailings, and evaluated the effects of meteorological changes, hydrology and hydrogeology. The objective of the laboratory study was to evaluate cover performance. A gravelly sand layer was selected for the sand base (30 cm), a compacted varved clay for the fine-grained soil cover (60 cm), and a fine to medium sand for the sand cover (30 cm). Describes test plots (max slope = 3:1) and column set ups.

Field Testing: The three-layer cover was effective in preventing percolation to the (column) tailings. Over three years of field testing, the clay remained close to it's construction water content. Infiltration was measured at 3.9% of the precipitation during the study.

Modeling: HELP was used for hydrologic modeling, and indicated that the cover would maintain integrity for a 20 yr projection. SEEP/W was used to simulate flow through the cover, and estimated that some percolation would occur. They modeled oxygen flux into the covered and uncovered tailings using POLLUTE. The modeled cover effectiveness was over 99.9%.

Laboratory: Laboratory columns indicated that the columns reduced pyrite oxidation, but to what extent is questionable.

ENGINEERED EVALUATION OF AMENDED FLY ASH FOR HYDRAULIC BARRIERS.
Bowders, J.J. Jr., Gabr, M.A., Boury, E.M., Baker, R.C.
Pitt94, V2, pg 226.

Summary: This paper reports laboratory efforts to characterize and optimize the physical properties of fly ash as a low hydraulic conductivity barrier to oxygen diffusion. Clay (30 %) and sand (30 %) amendments to fly ash (40%) produced a minimum hydraulic conductivity of 1.5×10^{-7} cm/s which repelled up to 80 % of the potential infiltrating water.

ON THE USE OF LOW SULFUR TAILINGS AS COVER TO PREVENT AMD: TECHNICO-ECONOMICAL ANALYSIS OF TWO CASES STUDY.
Bussiere, B., Lelievre, J., Ouellet, J., Bois, D.
Sud95, V1, pg 59.

WRITTEN IN FRENCH! One of the most serious environmental problem in the Canadian mining industry is the production of acid Mine drainage (AMD) by sulfide tailings. The objective of the main methods used to prevent the production of AMD is to eliminate the interactions between the constitutive elements of the reactions producing the acid, which are sulfides, water and oxygen. One of the most interesting way to do so is to use a multilayered cover in order to restrict the oxygen flow. Traditionally, such covers have been built from natural fine grain soils, but from an economical perspective the use of non reactive tailings could offer an attractive alternative. The authors have begun a technico-economical study on two existing mines in order to evaluate the possibility to separate the sulfur from the tailings and to use the non (or low) sulfur fraction so produced as a component of a multilayered cover. After presenting the sulfur separation test results, the main hydro-geotechnical properties of the non sulfur fraction are given. These properties were used as input for numerical simulations, which showed that these tailings can stay at a high degree of saturation over a long dry period. An economical analysis of the new method proposed is also included.

PRODUCTION AND EVALUATION OF LOW SULFUR TAILINGS AT INCO's CLARABELLE MILL.
Stuparyk, R.A., Kipkiek W.B., Kerr, A.N., Blowes, D.W.
Sud95, V1, pg 159.

Summary: In 1993, a plant test at INCO's Clarabelle Mill demonstrated that a substantial quantity of residual sulfides in the rock tailings can be removed with increased flotation in a slightly acidic pulp. This process leaves a large volume of potential inactive low sulfur tailings which can be used for cover and dam construction material. An extensive environmental evaluation is being performed on these low sulfur tailings (0.5%S) as well as INCO's main rock tailings (1%S) and total tailings (2.5%S).

Lab Tests: The evaluation involves both laboratory static and kinetic column tests plus field lysimeters tests on the three types of tailings. Static laboratory tests showed that INCO's total tailings are potentially acid generating whereas the acid generation potentials of the main and low sulfur tailings are uncertain.

Results: The column oxidation experiments showed that the total tailings generated acidic seepage with elevated concentrations of Ni, Fe, and SO_4 after 500 mm cumulative rainfall, or 20 weeks. The main tailings began to deviate from the low sulfur tailings by producing slightly acidic seepage after 1300 mm cumulative rainfall or 52 weeks. The $\%O_2$ and moisture content obtained from the field lysimeters in 1993 were used to estimate the sulfide oxidation rates of the three tailings. The rate of pyrrhotite oxidation for the total and main tailings was 4.73 and 7.97 $kg/m^2/yr$, respectively, while the low sulfur tailings oxidized at a rate of 0.98 $kg/m^2/yr$.

INCO's COPPER CLIFF TAILINGS AREA.
Puro M.J., Kipkie, W.B., Knapp, R.A., McDonald, T.J., Stuparyk, R.A.
Sud95, V1, pg 181.

Summary: Assessment of a number of closure options for the expanded tailings area, R-4. Describes closure options, including three cover systems utilizing low S tailings, which was adopted.

ASPECTS ON THE PERFORMANCE OF THE TILL COVER SYSTEM AT EQUITY SILVER MINES LTD.
O'Kane, M., Wilson, G.W., Barbour, S.L., Swanson, D.A.
Sud95, V2, pg. 565.

Summary: A soil cover research program investigated the long term performance of the soil cover system used for a waste rock dump. Predictive modeling was used to evaluate the soil cover in terms of the reduction of water infiltration and oxygen ingress. Field and laboratory programs provided data for evaluation of the present performance of the system. Field instrumentation focused on measuring in situ matric suction, water content, and temperature within the soil cover.

Results: The lower compacted layer remained at a high degree (>85%) of saturation. The capillary break was observed at the soil cover/waste rock interface.

A NEW OXYGEN CONSUMPTION TECHNIQUE TO PROVIDE RAPID ASSESSMENT OF TAILINGS REACTIVITY IN THE FIELD AND THE LABORATORY.
Nicholson, R.V., Elberling, B., Williams, G.
Sud95, V3, pg 999.

Summary: An innovative and efficient method to estimate oxidation rates in tailings by measuring the rate of oxygen consumption at the tailings surface was described. Field measurements and methods are presented in this paper, but the previous laboratory work was referenced. The implications were discussed in the context of the conceptual models of rate controls on oxidation rates in a field setting and the use of fine-grained covers to inhibit oxidation and acid generation.

Methods: Theory of oxygen consumption measurements, oxygen consumption and sulfide oxidation rates, and oxygen measurements described (experimental set-up w/ cylinders).

Results: The results of the field study indicated that oxygen consumption measurements provide a reasonable estimate of oxidation rates in sulfide tailings. There was good agreement between oxygen uptake and the production of sulfate resulting from sulfide oxidation. Placement of a 20 cm thick fine-sand layer produced rate reductions of more than 10 times. Rates of oxidation of fresh unoxidized tailings were as high as two times the rate observed in the existing tailings that had been exposed to the oxygen at surface for about eight years.

USE OF DEINKING RESIDUES AS COVER MATERIAL IN THE PREVENTION OF AMD GENERATION AT AN ABANDONED MINE SITE.
Cabral, A.; Lefebvre, G.; Proulx, M.F.; Audet, C.; Labbe, M.; Michaud, C.
Tmw97 pg 257 (1997)

Summary: The Eustis Mine site, located near Sherbrooke has been generating AMD that affects bodies of water crossing a highly popular touristic area. A type of capillary barrier constituted of residues from paper deinking processes, a spongy, partially saturated material, that absorbs large quantities of water was placed over a 1.6 hectare experimental plot at the Eustis site. Piezometers and lysimeters were installed. The profile of oxygen was measured at different locations and times to verify the efficiency of the cover material in preventing oxygen input. The hydraulic, geotechnical and water retention characteristics of the material are also being studied. Preliminary results are presented. Field data obtained so far are quite

encouraging: the concentration of oxygen remains below 2% at a depth of 0.4 m from the surface and are below the detection limit at the interface between the cover and the tailings. The quality of surface waters around the experimental cell has increased quite significantly 1 yr after construction.

Cover: tailings directly overlain by approximately 1.15 m deinking residue and approximately 0.35 m compost. Oxygen profile drops to <1% at only 0.4 m below the surface.

THE COVER RESEARCH PROGRAM AT EQUITY SILVER MINE LTD.
Wilson, G.W., Newman, L., Barbour, S.L.
Van97, V1, pg 197

Installation: Constructed a waste rock dump by regrading the side slopes and placing 0.5 m of compacted till overlain by 0.3 m of loose till and then revegetated. Water content, matric suction at temperature profiles were measured. The loose till provides an area of high storage capacity which allows rapid infiltration. The compaction of the till reduced the saturated hydraulic conductivity by almost three orders of magnitude, capable of maintaining saturation under high negative water pressures. Vegetation provides buffering and physical stability with respect to runoff, soil erosion and mass wasting. Slopes were designed to be 36.5 to 40%.

Modeling: The SoilCover model was used to predict surface fluxes and cover response for actual evaporation and transpiration. Computed oxygen fluxes were reduced by three orders of magnitude in the covered system, and that even under extremely dry conditions, the compacted till maintained a high degree of saturation. Long term data is not available yet.

OXYGEN CONSUMPTION ON SULFIDE TAILINGS AND TAILINGS COVERS: MEASURED RATES AND APPLICATIONS.
Tibble, P.A. and Nicholson, R.V.
Van97, V2, 647

Summary: The Oxygen Consumption Method was used at a variety of tailings impoundments in order to assess the range of values that exists and to develop a database of measurements. Test scenarios included; 1) tailings containing dominantly a)pyrite and b)pyrrhotite, 2) freshly deposited tailings with sulfide contents of 1%S, 15%S and 30%S, 3) thickened pyritic tailings with defined areas having exposure times from 0 to 10 years, 4) two soil covers, and 5) a tailings impoundment with a designed shallow water table.

The results showed that the range of measured rates spanned four orders of magnitude with typical values of 100 to 500 mol O_2/m_2a. In general, the high sulfide tailings exhibited the highest rates and the engineered cover exhibited the lowest rates. The sulfur content strongly influenced the oxygen consumption rates in fresh tailings. Oxidation rates measured for the thickened tailings exposed for ten years were about one third of those measured on an area of the same impoundment exposed for three to four years. Little difference in the range of values was evident among pyrite and pyrrhotite tailings with similar S%, and tailings with an average water table depth of only 1 m below ground surface. Example calculations illustrate various applications for the oxygen consumption measurements of the interpretation of water quality and buffer depletion rates in tailings.

Results: Oxygen consumption increased with increasing S-content and decreased as the tailings aged (except for relatively fresh tailings, <2yr, which tended to be saturated still). The simple

cover reduced oxygen consumption by and average of 10x, engineered cover 74x, raised water table 3x.

Applications: Estimates of pore water concentrations (Fe++, SO4, H+), metal loading rates and, buffer depletion rate.

CONSTRUCTION AND INSTRUMENTATION OF IN-SITU TEST PLOTS TO EVALUATE COVERS BUILT WITH CLEAN TAILINGS.
Aubertin, M., Bussiere, B., Barbera, J.M., Chapuis, R.P., Monzon, M., Aachib, M.
Van97, V2, 715

Summary: Experimental cells, including a (field) 3-layer composite cover of sand and tailings or silty soils, have been constructed to establish hydrologic conditions in and around the controlled volume. Monitored parameters include vol. water content, matric suction, temperature, and chemistry of the leachate. The configuration of the test plots is described with the construction sequence and instrument installation.

Cover Technology:
Dry cover costs range from 50-300k$/hectare, but are lower than the cost of other types of covers. The use of clean tailings allow for construction costs at the lower end, and possess mechanical properties that enhance the durability and performance of covers. Nice description of layers and their purpose in the system. Also provides a table of the properties of clean tailings used in their system.

Construction and Instrumentation:
Their field study was preceded by a laboratory study completed in 1995 (MEND report, Aubertin et al,., 1995). Field study was completed using test plots (6 cells with 5 different covers and 1 control). The coarse layers were composed of sand, the fine layer was either one of three thicknesses of clean tailings, natural silty soil, or a bentonite-clean tailings mixture. The paper includes a detailed description of how the cells were constructed on pg 721 and Table 2, pg 722. Monitored parameters were volumetric water content (Θ), the matric suction (Ψ), subsurface temperature, climatic conditions, and leachate chemical composition. Total construction costs were about 70k$US, and instruments totaled about 45k$US.

Results: The coarse layers maintained saturation ratios of 25-40%, while the fine layers were about 85%. An effective oxygen barrier is considered to be 80-90%, depending on thickness of the layer. Data collection was still in progress at the time of this paper.

UNSATURATED FLOW MODELING OF INCLINED LAYERS FOR THE ANALYSIS OF COVERS.
Aubertin, M., Chapuis, R.P., Bouchentouf, A., Bussiere, B.
Van97, V2, 732

Summary: This paper reviewed the behavior of a layered cover system, and then emphasized the important effect of cover inclination on moisture content and distribution. After a brief introduction on capillary barrier effects, the finite element model (SEEP/W) is presented with some calculations and results.

Unsat'd Flow: Unsaturated conditions imply that the hydraulic conductivity value (for a given material) changes according to the volumetric water content, which in turn, depends upon pressure

(matric suction). They used Richards equation, an extension of Darcy's law to describe the relationship.

Capillary Barrier Effect: decent description in terms of a cover system

Numerical Modeling: Used SEEP/W to simulate saturated and unsaturated flow for steady-state and transient conditions in 2-D. First modeled vertical flow (infiltration) only. Second, 2-D modeling of inclined layers.

Results: If the elevation difference between the upper and lower part of a continuous system approaches the air entry value (AEV) of the fine material, then the top portion may become unsaturated. The larger the elevation difference, the more difficult it will be to keep this layer close to saturation. Basically, you must have a low slope, or a fine material with a high AEV in order to maintain a stable water content profile.

EFFECTIVENESS OF COVERS BUILT WITH DESULFURIZED TAILINGS: COLUMN TESTS INVESTIGATION.
Bussiere, B., Nicholson, R.V., Aubertin, M., Servant, S.
Van97, V2, 763

Summary: This paper presented the results of a series of column experiments designed to determine the effectiveness of multi-layered covers made with desulfurized tailings. An additional objective was to evaluate the impact of the level of desulfuization on the behavior of the covers.

Experimental:

1) Materials characteristics-grain size, minerals, specific gravity, NP, AP, NNP. Hydro-geochem characteristics presented in Bussiere et al. (1997)
2) Column experiments-very detailed description of columns, instrumentation, configuration, and packing procedures

Results of Column Tests:

Includes equations for the Oxygen-consumption method. The desulfurized tailings multilayer covers reduced oxygen consumption by a factor of 20x, 5x, and 4x. The lowest S-content tailings reducing oxygen consumption to the greatest extent.

EVALUATION OF LOW SULFUR TAILINGS IN THE PREVENTION OF ACID MINE DRAINAGE.
Hanton-Fong, C.J., Blowes, D.W., Stuparyk, R.A.
Van97, V2, pg 835

Field: Lysimeters were installed in INCO's Copper Cliff Tailings Area. Pore water, pore gas, and tailings solids were collected semi-annually. The low S tailings maintained a neutral pH for the duration of the three years studied.

USE OF DEINKING RESIDUES AS COVER MATERIAL IN THE PREVENTION OF AMD GENERATION AT AN ABANDONED MINE SITE.
Cabral, A.; Lefebvre, G.; Burnotte, F.; Proulx, M.F.; Audet, C.; Labbe, M.; Michaud, C.
Van97, V3 pg 1109 (1997)

Summary: The Eustis Mine site, located near Sherbrooke has been generating AMD that affects bodies of water crossing a highly popular touristic area. A type of capillary barrier constituted of residues from paper deinking processes, a spongy, partially saturated material, that absorbs large quantities of water was placed over a 1.6 hectare experimental plot at the Eustis site. This paper presents the evolution of field measurements after 1 year from the beginning of the construction. Piezometers and lysimeters were installed. The profile of oxygen was measured at different locations and times to verify the efficiency of the cover material in preventing oxygen input. The evolution of the T withing the cover was also followed. The hydraulic and geotechnical characteristics of the material are also investigated. Field data obtained so far are quite encouraging: the concentration of oxygen remains below 2% at a depth of 0.5 m from the surface and below detection approximately 1 m below the surface. The quality of surface waters around the experimental cell has increased quite significantly. The field investigation is completed by a thorough lab program whose details are presented elsewhere.

DESIGN AND CONSTRUCTION OF A DRY COVER MADE OF TAILINGS FOR THE CLOSURE OF LES TERAINS AURIFERES SITE, MALARTIC, QUEBEC, CANADA.
Ricard, J.F., Aubertin, M., Firlotte, F.W., Knapp, R., McMullen, J., Julien, M.
Van97, V4, pg 1515

Summary: This paper presents the technical aspects related to the selection of material and the cover design, as well as construction related issues.

AMD Modeling: Modeled three scenarios to cover the tailings pile: 1. Cover with 0.5 m sand and gravel and vegetate, 2. Cover with 2 m non-acid production tailings and vegetate, 3. Cover with an engineered oxygen barrier and vegetate. Modeling determined that Scenario 1 would become acidic after 60 years. The total cost of scenario 1 was estimated at $12.6 million. Scenario 2 buys 100-150 years at $5.3 million. Scenario 3 buys more than 100 years at $5.2 million.

Scenario 3 was chosen and installed in 1995. Oxygen consumption, in situ water content, and water suction were measured at a total of 20 stations (10 on top, 10 on side slopes). Six months of measurements show an average of 86% saturation on top of the stack and 84% in the slopes. Oxygen consumption measurements showed an average 75 x reduction, up to 1000 x.

Dry Cover Design:

HELP and SEEP/W were used to evaluate the water budget of the site and the various drainages and seepage components. Values for grain size distribution, specific gravity, compaction curves, Atterberg's limits, sat'd hydraulic conductivity, water retention curves, oxygen diffusion, and freeze-thaw permeability were obtained. Results were "encouraging enough, on technical grounds, to allow for the decision to proceed."

Construction: more detail than I care to put here

Performance: 6 months of monitoring show an average of 86% saturation on top of the stack and 84% on the slopes. Oxygen consumption measurements (by Tibble and Nicholson, 1997) reduced oxygen flux by an average factor of 75, up to 1000.

FIVE YEARS AFTER COVERING TAILINGS AND WASTE ROCK WITH A COMPOSITE SOIL COVER: A CASE REVIEW AND WATER QUALITY PREDICTIONS AT THE MILLENBACH SITE

NEAR ROUYN-NORANDA, QUEBEC.
Woyshner, M.R.; St Arneault, C.; St Arnaud, L.C.
Van97, V4 pg 1673 (1997)

Summary: The Millenbach tailings site was decommissioned during 1990 and 91 by relocating 17500 m^3 of waste rock and fine material from various locations on site onto 0.66 ha of tailings, and covering with a composite clay cover designed to retard the ingress of oxygen. Pyrite was the primary sulfide mineral on site, and the majority was in tailings below the water table. This is beneficial because saturation inhibits oxidation. The waste rock above the tailings was unsaturated and showed less than 5% pyrite. This pyrite was therefore assumed to be readily available for oxidation, but limited to oxygen exposure by a composite clay cover (30 cm coarse sand, 50 cm compacted clay, 30 cm fine sand, top soil).

For two years after decommissioning, levels of sulfide oxidation products were elevated. Following this disturbed period, iron, sulfate and acidity showed a steady decline, which was attributed to porewater flushing and dissolution of secondary minerals. The flushing and dissolution period should follow a two step process: 1) flushing of preferential flow paths in the waste rock, when significant improvement in effluent water quality are expected; and 2) flushing of the tailings and remaining waste rock. The length of the flushing and dissolution period was predicted by two methods: 1) extrapolating piezometer monitoring data, and 2) dissolution of gypsum, a secondary mineral precipitated in the tailings and waste rock prior to decommissioning. The period was estimated to be in the range of 20 to 40 years, but significant improvements in effluent water quality are expected in roughly 8 yrs, when preferential flow paths in the waste rock are flushed. Sulfide oxidation products in the effluent water should gradually decline to ultimately resemble naturally occurring levels. Long-term effluent groundwater quality are predicted around 9 mg/L iron, 31 mg/L sulfate and neutral pH, resembling uncontaminated background water quality.

A RAPID KINETIC TECHNIQUE FOR MEASURING THE REACTIVITY OF SULFIDE WASTE ROCK: THE OXYGEN CONSUMPTION METHOD.
Nicholson, R.V., Scharer, J.M., Anderson, M.E.
Report to MEND, (1997) Executive summary and table of contents only.

The oxygen consumption method, tant was initially developed as a tool to assess reactive tailings in the laboratory and field was adapted to measure reaction rates on waste rock samples in short term experiments. The technique provides reaction rate data that can complement data from humidity cells. Many samples can be processed simultaneously and, therefore, a larger body of kinetic data can be developed for cost-effective statistical assessment and interpretation. This study represents the development of the technique, demonstration of the interpretation and a comparison among several waste rock types from selected mines and exploration projects.

An experimental method was developed to assess the rate of oxygen consumption in sulfide waste rock. The technique involves placing a reactive rock sample in a sealed chamber and measuring the gas-phase oxygen concentration over a period of 2 to 3 days. A research program was undertaken to investigate the influence of particle size, sulfur content, temperature and inoculation with *Thiobacillus ferrooxidans* on the rate of oxygen consumption of waste rock samples. Waste rock and drill core samples were collected from a number of locations and the oxygen consumption rates of different rock types were compared and contrasted.

Particle size effects were studied over a range of sizes from 0.07 to 100 mm. The oxygen consumption rate was a function of $1/d^n$, where n was generally between 0.8 and 1.6 for uninoculated samples (0.3-

0.7 for inoculated). T. ferrooxidans increased the rates (more detail in abstract). The oxygen consumption rate consistently over estimated the rate of sulfate release for samples containing pyrrhotite. Partial oxidation of sulfide in the pyrrhotite leading to enrichment of sulfur on the surface may account for 60 - 90 % of the total oxygen consumed by pyrrhotite. Samples containing pyrite as the dominant sulfide mineral exhibit oxygen consumption rates that correlate well with the amount of sulfate released.

MANAGEMENT OF RESIDUAL PYRITE IN MINE TAILINGS.
Muller, G., Dorey, R., Willow, M.
Tailings and Mine Waste, 1998, pg 67

Summary: The addition of a pyrite flotation circuit to recover a portion of the residual pyrite from the whole tailings stream and separate management of pyrite concentrates and flotation tailings were proposed. Flotation tailings were deposited in the impoundment interior. Pyrite concentrates were deposited within the tailings pond under subaqueous conditions where they were buried and encapsulated within flotation tailings slimes. The paper discussed the methods used to evaluate rates of oxidation and the effects of the proposed operating modifications on tailings oxidation.

Methods: Rates of oxygen diffusion were evaluated with a method presented in Collin (1987), although, diffusion equations appear on pgs 68 and 69. Moisture content profiling was evaluated using the HELP model. The cover was predicted to reduce the rate of oxidation by approximately 90%.

DEVELOPMENTS IN THE USE OF DEINKING RESIDUES IN COVER SYSTEMS FOR ACID GENERATING MINE TAILINGS.
Cabral, A.; Lefebvre, G.; Burnotte, F.; Proulx, M.F.; Racine, I.; Audet, C.
Tmw98 pg 379 (1998)

Summary: Pulp and paper industries produce deinking residues in great quantities. Most of it is presently landfilled at great costs. Due to its particular hydraulic characteristics, including a high retention capacity, this material can be recycled and used in different geoenvironmental applications, such as capillary barriers in cover systems for Mine tailings. A capillary barrier constituted of deinking residues was placed over two tailings sites near Sherbrooke, Quebec. Oxygen, CO_2 and methane profiles showed that the O_2 concentration 20 cm below the surface was approx. zero and that the concentrations of CO_2 ad CH_4 increased with time. Water content, T and organic percentage profiles were determined in the filed. Oxygen diffusion tests performed in the lab confirmed the field data in showing that migration: diffusion coef in the range of 3.5 m^2/yr to 110 m^2/yr were obtained. The lower values are associated with degrees of saturation in the range of 85%, whereas the higher values are associated with degrees of saturation in the range of 76%. During these tests, oxygen consumption and CO_2 generation were observed, meaning that the deinking residues may also work as an oxygen consuming barrier. Suction tests under different conditions yielded air entry values in the range of 30-65 kPa. Part of the physico-chemical characterization of the material is presented.

GEOCHEMICAL BEHAVIOR OF A MULTI-LAYERED COVER COMPOSED OF DESULFURIZED MINE TAILINGS.
Benzaazoua, M., Bussiere, B., Nicholson, R.V., Bernier, L.

Tailings and Mine Waste, 1998, pg 389

Summary: This paper reports the behavior of desulfurized tailings as a moisture-retaining layer in the cover. A series of column experiments showed that contaminant production is reduced significantly when a cover made of desulfurized tailings is placed over the reactive tailings. The oxidation rates, measured with the Oxygen-consumption method are significantly lower for the columns with a multi-layered cover. This study showed the potential of using desulfurized tailings as a component of a multi-layer cover for limiting AMD from sulfidic tailings.

Methods: 1) Columns-excellent description of column configuration and oxygen consumption measurement
2) Chemical and mineralogical properties-effluent pH/Eh, ICP, AES, XRD
3) Geochem predictive model-used to calculate the equilibria in the effluent
4) Oxygen consumption-cites Elberling et al. (1994) and Elberling and Nicholson (1996)
5) Physical properties-porosity, specific gravity, grain size, AEV, AP/NP/NNP

Results: Effluent pH on covered columns remained neutral over one year. Cover reduced oxidation rate by a factor of 50 or so, depending on degree of desulfurization. Construction costs for this multi-layered cover, including revegetation were estimated at $90k/hectare, rather than $231k to $415k for multi-layer covers that do not use desulfurized tailings.

RECLAMATION OF THE PANNA MARIA TAILINGS IMPOUNDMENT:
Strachan, C.L.; Raabe, K.L.
Tmw98 pg 825 (1998)

Summary: Panna Maria Uranium Operations started reclamation of the Panna Maria U tailings impoundment following mill shutdown in 1992. The closure plan included a multi-layered cover over the regraded tailings surface which was designed for long-term isolation of tailings, reduction of radon emanation to regulated levels, and reduction of infiltration for ground water protection considerations. The cover was constructed with on-site soils and off-site clay amendments. Reclaimed surfaces were designed to provide acceptable erosional stability. The cover was constructed with a slope of 0.5%, and regraded embankment slopes were constructed with a max slope of 20%. All reclaimed slopes were covered with topsoil and revegetated. A riprap-lined outlet channel was constructed to convey runoff from the reclaimed impoundment.

Cover: A 1' infiltration barrier comprised of compacted bentonite, with a hydraulic conductivity $< 5 \times 10^{-8}$ cm/s, in 6" lifts. The middle layer was a 2' thick zone of compacted on-site materials to provide additional radon attenuation and protection of the infiltration barrier (6" lifts). 1' topsoil and vegetation.

DESIGN CONSTRUCTION AND MONITORING OF A WASTE ROCK COVER USING PULP AND PAPER RESIDUES.
Cabral, A.; Burnotte, F.; Lefebvre, G.; Amyot, G. Lacasse, G.
TMW99, pg 405 (1999)

Abstract: A waste rock fill potentially generating acid Mine drainage near Woburn, Quebec, Canada, was capped by a cover system including a capillary barrier constituted of P&P (deinking)

residues. The results of tests conducted during construction as well as the first results pertaining to the monitoring program are presented. These results seem to indicate that the capillary barrier is performing as required: the deinking residue layer is keeping a high degree os saturation and oxygen is not reaching the bottom of the barrier (thus AMD is not being produced).

CLEAN TAILINGS AS COVER MATERIAL FOR PREVENTING ACID MINE DRAINAGE: AN IN SITU EXPERIMENT
Bussiere, B.; Aubertin, M.
Sud99, V1, pg 19

Abstract: AMD is the main environmental problem for the mining industry. In recent years, there has been a lot of effort devoted to studying the behavior of covers with capillary barrier effects (CCBE). These covers are used to control the generation of AMD by limiting the oxygen diffusion flux. Cost is one of the main concerns for the application of this technology. Accordingly, one should look for means of increasing the efficiency and reducing the construction costs of covers. In that perspective, it has been proposed a few years ago to use non reactive tailings (or clean tailings) as the fine layer material in CCBE. This paper presents the results of an in situ investigation where clean tailings have been used for the moisture-retaining layers in experimental cells with covers. Different techniques were used to evaluate the efficiency of the covers, including water content profiles, percolating water quality and Oxygen Consumption tests. The water content profile showed that the degree of saturation in fine material layers remained high (usually above 85), which was necessary for limiting the diffusion of oxygen. During the experiment the pH of the percolated water stayed between 6 and 7 for four of the five cells. The Oxygen Consumption tests have also demonstrated that after the first year, the oxygen flux through the covers became very low compared to the control (uncovered) cell. The different results lead to the conclusion that clean tailings can be used in CCBE that are efficient in controlling the production of AMD.

PERFORMANCE OF A DRY COVER MADE OF TAILINGS FOR THE CLOSURE OF LES TERRAINS AURIFERES SITE, MALARTIC, QUEBEC, CANADA
Ricard, J.F.; Aubertin, M.; McMullen, J.; Pelletier, P.; Poirier, P.
Sud99, V1, pg 155

Abstract: Since 1996, Barrick Gold Corporation's Les Terrains Auriferes (LTA) tailings site has been the subject of a detailed study - MEND Project 2.22.4 - aimed at assessing the performance of a composite cover placed on the acid-generating tailings impoundment. The full-scale composite cover was built in the winter of 1996 on the 60 hectare site. Alkaline Mine tailings were used for the fine material layer.

In addition to being the first full-scale cover of this type (e.g. oxygen barrier) in Canada, this project offers the added advantage of using Mine tailings, a waste product. The main objective of this project is to describe the various phases of the LTA project, from the initial conceptual design of the cover to the final construction and monitoring. Over a period of three years (1996-1998), the LTA cover has reduced the tailings oxidation rate by an average of 95%, and the oxygen barrier layer has kept a yearly saturation level of 85% or more.

EFFECT OF DIFFERENT COVER, COVER/TAILINGS MIXES AND CAPILLARY BREAKS ON WATER DYNAMICS WITHIN TAILINGS AND PAPER WASTE COVER MATERIALS.

Hanselman, K.; Courtin, G.M.
Sud99, V2, g 801 (1999)

Abstract: One of the major concerns associated with the application of a vegetated soil cover over Mine tailings is the potential for contamination of the cover material(s), through capillary movement of contaminated tailings pore water. Evaluation of potential cover materials requires an understanding of the dynamics of water movement within both the tailings and the cover material, so that the risk of contamination can be assessed, and the necessity of a capillary break layer can be determined. Experimental design involved the use of a wind tunnel to simulate natural air movement across the soil-air interface. Columns were filled to capacity with the substrate under investigation, saturated, and allowed to drain to field capacity. Evaporation rates over time were plotted to reveal the patterns of water movement. The columns were kept in the wind tunnel until no further change in water loss occurred or until the trent of water loss was observed, at which time, moisture retention with depth was determine. Overall, St. Mary's paper waste sludge (STM) is a more effective cover than the E.B. Eddy paper waste sludge (EBE). STM has a higher water holding capacity and higher water retention because the surface dries out and serves as a mulch. STM also entrained very little tailings capillary water in contrast to EBE. Evaporation of STM over a capillary break differed little from when th e cover was in direct contact with the tailings whereas EBE dried out more rapidly. Finally, STM and EBE/tailings blends hold on to less water owing to increased evaporation, but the STM blend still has a higher water retention compared to the EBE blend. In light of these findings the characteristics of STM as a cover material over tailings are superior to those of EBE.

A2.3. Clay

A COVER SYSTEM FOR A POTENTIALLY ACID FORMING WASTE ROCK DUMP IN A DRY CLIMATE.
Williams, D.J., Wilson, G.W., Currey, N.A.
Tailings and Mine Waste, 1997, pg 231

Summary: Covering a potentially acid forming waste rock dump located in a dry climate presents conflicting challenges. While it might be desirable to maximize rainfall runoff and so minimize infiltration into the dump, this will also threaten the integrity and effectiveness of the cover during high intensity, if infrequent, seasonal rainfall events. Excessive, high velocity runoff will result in erosion and a gradual drying out of the cover. This will render it less effective in limiting rainfall infiltration and air entry. A proposed cover system is described which aims to balance rainfall with water storage within the cover, evaporation from the surface, and transpiration by vegetation.

EQUITY SILVER MINE- INTEGRATED CASE STUDY
Aziz, M.L.; Ferguson, K.D.
Van97, V1, pg 183 (1997)

Summary: The Equity Silver Mine is a closed open pit and underground gold-copper-silver Mine located in the central interior of BC. ARD was discovered leaching from the waste dumps in late 1981. Extensive ARD collection and treatment systems were emplaced and continually upgraded to ensure the protection of the environment. With the closure date approaching, a

large field-scale test of a compacted clay cover was evaluated on the Southern Tail waste dump in 1990. Compacted clay covers were progressively constructed on the remainder of the resloped waste rock dumps between 1990 and 1994. The cover was designed to reduce the infiltration of water and air to the waste rock resulting in decreased ARD production and lower lime treatment costs.

Evaluation of the cover performance has been ongoing since 1991 and consists of the measurement of water and oxygen infiltration. The results consistently show that the average infiltration has remained below 5% (0.2 - 12%). Oxygen concentrations below the cover have decreased to a few percent. Estimated cost at $35,000/hectare.

THE RECLAMATION PROJECT AT SAXBERGET MINE, SWEDEN.
Lindvall, M.; Lindahl, L.A.; Ericsson
Van97, V3 pg 1389 (1997)

Summary: This paper focuses on the planning, execution and follow-up of the reclamation of the mill tailings area, this being the potentially most important contaminant source. As the tailings ponds are located on a highly permeable glacial formation, flooding of the deposits was impossible. Therefore, a solution including a composite layer cover was selected. A number of alternative cover materials were considered, including fly ash cement and sewage sludge, as the sealing layer. The best alternative, however, proved to be the use of 30 cm compacted glacial till with high clay content in the sealing layer, and with unspecified glacial till as the protection layer. The results obtained so far point towards success. Oxygen measurements under the cover show that the oxygen transport to the tailings is almost eliminated by the cover. Goals on hydraulic conductivity have been met resulting in a significant reduction of infiltration. Infiltration rate, based on lysimeter readings, were close to or better than 5×10^{-9} m/s. Oxygen concentrations below the cover have dropped to <0.5%. Costs estimated at $14 CND/m^2.

BERSBO PILOT PROJECT-PHYSICAL BEHAVIOR SEVEN YEARS AFTER COVERING THE WASTE ROCK PILES
Lundgren, T.
Van97, V3, pg 1419

Abstract: Being the first full scale project in Sweden of remediating sulfidic wastes according to the dry cover method, the measures have been followed up since 1989. The mining waste, consisting to 95% of waste rock, was at the time 90 to 600 years old. The remediation works included concentration of the waste rock to two piles reducing the exposed area to 50% and dumping 1/3 of the waste volume under the ground water table in old Mine shafts. The dry cover consists of a sealing layer of compacted clay (0.5 m) on one of the piles and cement stabilized fly ash (0.25m) on the other pile, both covered by a protective cover of 2 m of glacial till.

The follow up studies have been concentrated on the effect of the cover on water balance, oxygen transport and quality of discharged water. The results show that both covers act as good water barriers and the clay liner also acts as a good oxygen barrier. The cementitious liner, however, is more pervious to oxygen than the clay liner. The water percolation has been significantly reduced to less than 3% (clay liner) and 12% (cementitious liner) of what it was prior to covering. The oxygen transport is reduced substantially through the clay liner. The cementitious liner, however, is a less good oxygen barrier, partly due to the higher permeability, partly due to the not fully saturated sealing layer. The performance of the

oxygen barrier has proven to be sensitive to the existence of leakage paths allowing advective transport of air to the deposit.

FIVE YEARS AFTER COVERING TAILINGS AND WASTE ROCK WITH A COMPOSITE SOIL COVER: A CASE REVIEW AND WATER QUALITY PREDICTIONS AT THE MILLENBACH SITE NEAR ROUYN-NORANDA, QUEBEC
Woyshner, M.R.; St-Arneault, C.; St-Arnaud, L.C.
Van97, V4, 1673

Abstract: The Millenbach tailings site was decommissioned during 1990 and 1991 by relocating 17500 m^3 of waste rock and fine material from various locations on site onto 0.66 hg of tailings, and covering with a composite clay cover designed to retard the ingress of oxygen. Pyrite was the primary sulfide mineral on site, and the majority was in tailings below the water table. This is beneficial because saturation inhibits oxidation. The waste rock above the tailings was unsaturated and showed less than 5% pyrite. This pyrite (as well as other sulfide minerals in minor amounts) was therefore assumed to be readily available for oxidation, but limited to oxygen exposure by a composite clay cover.

For two years after decommissioning, levels of sulfide oxidation products were elevated. Following this disturbed period, iron, sulfate and acidity showed a steady decline, which was attributed to pore water flushing and dissolution of secondary minerals. The flushing and dissolution period should follow a two step process: 1) flushing of preferential flow paths in the waste rock, when significant improvements in effluent water quality are expected; and 2) flushing of the tailings and remaining waste rock.

The length of the flushing and dissolution period was predicted by two methods: 1) extrapolating piezometer monitoring data, and 2) dissolution of gypsum, a secondary mineral precipitated in the tailings and waste rock prior to decommissioning. The period was estimated to be in the range of 20 to 40 years, but significant improvements in effluent water quality are expected in roughly 8 years, when preferential flow paths in the waste rock are flushed. Sulfide oxidation products in the effluent water should gradually decline to ultimately resemble naturally occurring levels. Long-term effluent ground water quality are predicted around 9 mg/L iron, 31 mg/L sulfate, and neutral pH, resembling uncontaminated background water quality.

A2.4. Geosynthetic Clay Liners

COST EFFECTIVE AND EFFICIENT SOLUTIONS WITH GEOSYNTHETIC CLAY LINERS FOR SEALING APPLICATIONS IN THE MINING INDUSTRY.
Stewart, D. vonMaubeuge, K.
Tmw97 pg 223 (1997)

Summary: Geosynthetic clay liners are a new and rapidly developing class of geosynthetic composites that can be easily transported and rolled out like a carpet to provide a durable impermeable liner with a permeabilityequivalent to much thicker, and more difficult to build compacted clay liners. This paper shall show the advantages of GCL's versus other sealing elements such as CCL's not only based on technical aspects but also on economic advantages offered by GCL's. The further benefit of increased containment volume can easily be calculated by the reader so the entire cost effect can be determined on a project to project

basis. The second section of this paper will outline the successful use of GCL's in mining applications. This presentation will not only demonstrate the technical aspects and compare laboratory test results, but will also outline field experiences with geosynthetic clay liners. Large scale project applications will be outlined to contribute to the fact that GCL's can reduce costs for the mining industry without compromising the integrity of the sealing system.

ENGINEERED UPLAND SULFIDE TAILINGS MANAGEMENT FACILITY.
Sevick, G.W.; Paruvakat, N.; Black, K.P.; Hockley, D.
Tmw98 pg 93 (1998)

Summary: This paper examines the various types of upland containment facilities investigated for the disposal of Crandon Project tailings. Based on the studies performed, a drained containment facility with a base composite liner, a leachate collection system and a dry cap with a composite hydraulic barrier was selected (1' fine soil, GCL and 60 mil HDPE). Included in the paper is a discussion of the modeling completed for water movement through the final cover and within the tailings mass to predict percolation rates through the base liner. The extensive modeling showed that the base liner is critical in the control of percolation throughout the operation and tailings dewatering period, and that the final cover is critical in the control of oxygen transport and percolation from the facility in the long-term. The paper also discusses oxygen transport and geochemical modeling, and the solute transport modeling completed to assess compliance with applicable groundwater standards.

PERFORMANCE ISSUES RELATED TO GEOSYNTHETIC LINERS AT MONTICELLO, UTAH.
Brennecke, D.F.; Corser, P.G.
Tmw98 pg 351 (1998)

Summary: The US DOE Grand Junction Office is remediating a CERCLA site that includes cleanup of a former uranium millsite in Monticello, Utah, and placement of more than 2.3 million cubic yards of U-contaminated materials in a double lined repository that was constructed with two composite geosynthetic clay/ 60 mil HDPE liners. A triple lined evaporation pond was also constructed with a seven layer geosynthetic liner system. Liner performance issues are evaluated against the benefits and limitations of a comprehensive construction quality assurance program combined with a post-construction leak location survey.

GEOSYNTHETIC CLAY LINERS FOR THE MINING INDUSTRY.
Miller, B.; Hornaday, C.
Tmw98 pg 361 (1998)

Summary: Geosynthetic clay liners (GCLs) are manufactured barrier layers containing high quality sodium bentonite clay attached or adhered to geotextiles or a geomembrane. The low permeability and high strength of the GCL make it an ideal replacement for low permeability soil or clay liners used in mineral extraction and processing containment applications. Some of the advantages of utilizing a GCL versus compacted clay in containment applications include; a permeability of 5×10^{-9} cm/s and corresponding better composite liner leakage protection, greater resistance to desiccation, differential subsidence and freeze-thaw, and lastly, the ease and speed of installation. A number of important case studies related to the mineral extraction and processing industry are detailed. These case studies include using GCL in two large reclamation capping projects, as a secondary liner in three gold heap leach

pads, and as a composite liner in a dam for storm water runoff control.

CASE STUDIES ON THE USE OF GEOSYNTHETIC CLAY LINERS IN MINING RECLAMATION
Miller, B.
Tmw99 pg 353

Abstract: GCLs are manufactured barrier layers containing a high-quality sodium bentonite clay attached or adhered to geotextiles or a geomembrane. The GCL's low permeability and high strength make it an ideal replacement for low permeability soil or clay liners for mining reclamation projects. This paper will detail a select number of case studies where GCL has been utilized in mining reclamation projects in the United States. These case studies range from a simple GCL-bentonite slurry wall tie-in to a large 74 hectare Superfund reclamation cap. The case studies will summarize, where appropriate, project-specified design, regulatory, installation, schedule, and economic issues involved with each project.

CONSTRUCTION QUALITY ASSURANCE OF A GEOSYNTHETIC CLAY LINER AT HIGH ELEVATION
Brewer, W.; Reimer, D.; Wienecke, C.; Morfitt, B.; Frobel, R.
Tmw99 pg 359

Abstract: A GCL was used to cap the 178,000 m^2 heap leach pad at the Summitville Mine Superfund Site in Colorado. due to the remote location, elevation and site conditions, unique problems were encountered for the construction of the heap leach pad cap system and subsequently for the construction quality assurance for the project. This paper addresses some of these unique problems encountered to allow the readers to consider them in regard to projects with similar site conditions.

A2.5. Geotextile Liners

RIPRAP ROCK DURABILITY VERSUS ROCK QUALITY: A CASE STUDY.
Thornton, C.I.; Steven R.A.; Johnson, T.L.
Tmw97 pg 283 (1997)

Summary: A riprap layer is often placed atop reclaimed Mine tailings repositories to provide long-term erosion protection. The stones that comprise the riprap layer are evaluated by the performance of standard rock quality tests. The composite of the test scores indicates the general rock quality that in turn is used as an indicator of the long-term rock durability. Rock samples were collected from a reclaimed impoundment. Site monitoring determined that individual stone particles were degrading at an accelerated rate. The samples were subjected to rock quality tests, petrographic examination, and a series of proposed durability tests. The rock quality tests and petrographic evaluations indicated that the rock was suitable for erosion protection. However, the durability evaluation suggested that the rock may disintegrate in 130 to 272 years. It is suggested that a) a rock durability assessment procedure be formulated, b) long-term surveillance/monitoring programs be instituted for U mill tailings impoundments, and c) site specific freeze/thaw cycles be considered for site analysis.

DESIGN OF THE TAILINGS DISPOSAL FACILITIES FOR BATTLE MOUNTAIN GOLD COMPANY'S CROWN JEWEL MINE NEAR OROVILLE, WASHINGTON.
Shuri, F.S.; Brown, M.L.; Schumacher P.M.
Tmw98 pg 35 (1998)

Summary: The development of the design of the Tailings Disposal Facility for this planned gold Mine is discussed in technical as well as regulatory terms. The ultimate facility provides containment for 9.1 million tons of tailings between two embankments, 185' and 95' high. The regulatory design process has been much more extensive than on any known similar project of this magnitude. As a result, the tailings containment system is one of the most conservative tailings designs developed to date; it includes cyanide destruction, drained tailings, double geosynthetic liners with leak detection and collection systems, and embankments constructed with downstream raises. The sequence of events leading to the current design, including promulgation of new state legislation governing metal mining is described.

COVERING OF SOFT MINE TAILINGS.
Neukirchner, R.J.; Lord, G.G.
Tmw98 pg 399 (1998)

Summary: The historically ponded area of the Consolidated Tailings Pile at the Eagle Mine Superfund site presented difficult conditions for completion of the required covering and capping activities. The extremely high moisture content and low strength of the soft tailings would not even support low ground pressure construction equipment. Closure of the HP area required the placement of 2 to 12' of regraded and relocated material and, after 90% of the primary settlement was achieved, installation of a multi-layer cap. After a field test with a woven geotextile was unsuccessful, a plan to use a geogrid material with a drainage layer was developed for winter placement using the frozen surface to support the geogrid and drainage layer. The successful placement of that initial HP area cover provided access for additional material (fill) placement and, after the required settlement had occurred, offered a stable base for cap placement.

INDUSTRY ACTIVITIES FOR IMPROVING MATERIAL AND INSTALLATION SPECIFICATIONS FOR GEOMEMBRANES
Thomas, R.W.
Tmw99 pg 367

Abstract: The last five years have seen a focused effort to improve the quality of geomembrane specifications. The activities for Manufacturing Quality Control include the withdrawal of Standard 54 by the National Sanitation Foundation, the developmental efforts of standard specifications for polyethylene geomembranes and the new standard specification for poly vinyl chloride. Recent Manufacturing Quality Assurance activities include corporate specifications for large companies, in-plant sampling, and the accreditation of independent laboratories. Installation activities include certification of third party construction quality assurance technicians and the formation of an association of geosynthetic installers. There is also a new destructive seam testing protocol that may reduce the number of destructive seam tests, and thus the number of holes cut into geomembranes. All these efforts have a common goal to improve the quality of geomembrane installations while simplifying the specifications required to ensure high quality.

POIRIER SITE RECLAMATION PROGRAM
Lewis, B.A.; Gallinger, R.D.
Sud99, V2, pg 439

Abstract: Poirier was an underground copper and zinc mine located in Northern Quebec. The Mine operated between 1965 and 1975, when it closed due to low copper prices and high production costs. The property was sold, and when the last owner could not fulfil their responsibilities to remediate the site, Rio Algoma Limited assessed the property and developed a restoration plan.

There are less than 5 million tonnes of acid-generating tailings, which has contributed acidity and metals to the local watershed. The Kananewesig and Kistabiche Creeks have been affected by effluent from the site. In developing closure alternatives for the site, the Ministries of the Environment and Natural Resources were consulted. The final closure option incorporates the placement of all reactive material in the tails basin and installation of a geomembrane liner over the main tailings deposit, with a one meter soil layer to protect the liner. The liner will substantially reduce infiltration through the cover and will limit oxidation of the tailings thereby reducing the release of metal loadings. The environmental effect of the residual seepage was assessed from an ecological risk perspective. The Reclamation Plan has been accepted by the Quebec Government, and work commenced in 1998 to restore the site.

A2.6. Inducement of Hardpans

Pitt94 Ahmed, S.M. (1994) Surface chemical methods of forming hardpan in pyrrhotite tailings and prevention of the acid Mine drainage. V2.

Abstract: This work was undertaken to identify conditions under which hardpan could be formed in pyrrhotite rich tailings using surface chemical methods and to check the susceptibility of the synthetic hardpan to atmospheric oxidation and acid formation.

Pyrrhotite hardpan was first grown on a small scale by surface chemical and electrochemical methods, after treating the FeS-rich tailings with a dilute solution of FeII, pH adjustment, and curing for several weeks in the presence of air. This synthetic hardpan was similar to the pyrrhotite hardpans formed under natural conditions, consisting of FeS grains embedded in iron oxyhydrate (goethite) matrix.

Attempts were then made to grow similar hardpans on a large scale with FeS columns of 3 ft length and 4 in diameter. The effects of surface oxidation of FeS in air, FeII treatment, humidity, pH and a water head (2 in) on the hardening of tailings and acid formation have been examined. Hardening was confined mainly to the outer layer of the tailings exposed to air; the inner core remained soft and retained most of the FeII in the unoxidized form. The pH, dissolved iron concentration, and redox potentials of the percolant solutions were monitored. Most pronounced was the effect of maintaining 2 in of water head on the tailings, which prevented the oxidation of FeS and acid formation completely. The data have been examined in light of the Eh-pH diagram of the FeS_2-FeS-Fe_2O_3 system in equilibrium with water. It is inferred that the FeS system can be stabilized through formation of iron oxide and other less soluble compounds such as iron silicates on the surfaces. Methods of improving kinetics of hardpan formation have been suggested.

2716 Ahmed, S.M. (1995) Chemistry of pyrrhotite hardpan formation. Sud95, V1, 171.

Abstract: Hardpans formed naturally in pyrrhotite-rich tailings at the Mine disposal sites, normally consist of FeS grains cemented in lepidocrocite and goethite structures of iron oxyhydrates. It was possible to make high density, pyrrhotite hardpans with the same structure on a small scale by electrochemical treatment of pyrrhotite rich tailings. Attempts to make such structures surface chemically resulted in two distinct types of hardpans depending on the experimental conditions. A reddish brown variety was formed as an outer layer in the fully oxidizing zone and a gray colored variety formed in a reduced state with ferrous iron in the non-oxidizing zone. Several other forms of hardpans with intermediate oxidation states were also identified. The gray and the fully oxidized forms of hardpans, if dense, are stable in air. All other hardpans with FeS partly exposed get readily hydrolyzed in contact with water producing iron hydroxides and acid. The electrochemically formed hardpan, however, was an exception in stability. Pyrite hardpans are rare in occurrence and different in structure. The chemistry of hardpan formation and structures have been discussed and the possibility of using such formations in the prevention of sulfide oxidation and acid drainage has been examined.

2745 Chermak, J.A.; Runnells, D.D. (1997) Development of chemical caps in acid rock drainage environments. Mining Engineering. p 96-97.

Abstract: Sulfide-bearing waste rock, ore and tailings have the potential for generating acid rock drainage when exposed to an oxidizing environment. The possibility exists of utilizing the acid produced to react with lime and/or limestone to form a self-sealing cap on the reactive waste rock and tailings. Laboratory column experiments were conducted using acid-generating waste rock with a surface amendment of limestone and/or lime. Artificial rainwater was introduced and allowed to drain through the columns. Results demonstrated that the limestone and lime reacted with the acidic rock, resulting in the precipitation of a hardpan layer of gypsum and amorphous iron oxyhydroxide at the surface. The hardpan layer significantly reduced the effective permeability of the column. Based on the results of this study, it should be possible to create hardpan layers as chemical caps to significantly reduce the infiltration of rain water and snow melt into acidic waste rock or tailings material in the field. Unlike traditional capping methods, e.g., clay and HDPE covers, chemical caps should be self-healing.

Tmw97 Lin, Z.; Herbert Jr., R.B. (1997) Formation of Fe precipitated layers in a mill-tailings deposit: Barriers to metal mobilization. pg. 237.

Abstract: Fe precipitated layers in an inactive sulfide-containing mill-tailings deposit form at a depth where carbonate is present and the leachate pH increases. The Fe precipitates consist mainly of goethite, and lesser amounts of lepidocrocite and other Fe hydroxides, and traces of Ca, Cu, Fe, and Zn sulfates. The Fe precipitates fill the intergrain pores, and cement the tailings matrices, leading to a reduction of the tailings porosity. In addition, dissolved elements, e.g. As, Cu, Zn, are retained by Fe oxyhydroxides through adsorption and co-precipitation. as a result, the Fe precipitated layers behave as a barrier to restrict the movement of oxygen, and act as an accumulation zone of heavy metals and As. The extent of sulfide oxidation, and the concentration of dissolved metals, is greatly reduced below the Fe precipitated layers.

Van97 Tasse, N.; Germain, D.; Dufour, C.; Tremblay, R. (1997) Hard-pan formation in the Canadian Malartic Mine tailings: implication for the reclamation of the abandoned impoundment. V4, pg. 1797.

Abstract: The Canadian Malartic impoundment features a layer cake structure with 6.9 Mt of mildly reactive tailings at the base, generated by gold mining, and 1.2 Mt of strongly reactive, sulfurous, tailings at the top, produced from Ni-Cu extraction. Metal cycle analysis indicates that the quantity of dissolved ions directly related to sulfide oxidation is small, compared to that mobilized by the dissolution of alteration minerals. Near surface reactive sulfides have already reacted, and oxygen access to fresh sulfides is limited by the presence of a fairly continuous hardpan layer. Heavy metals show little mobility within and around the impoundment periphery, as a result of precipitation, coprecipitation, or adsorption. Runoff in direct contact with altered tailings devoid of any significant neutralizing capacities, generates the most contaminated waters, but there are no significant accumulations of such waters.

The acid neutralizing capacity of the site is about three times the acid producing capacity. Given the observed contaminant cycle, the remediation objectives could be reduced to an aesthetic problem, keeping in mind that the hardpan, a natural barrier against alteration, should not be disturbed. Thus the surface impoundment was leveled and revegetated with minimal disturbance, keeping the natural drainage pattern developed over the site, and avoiding soil disruptions at depths larger than a few tens of centimeters. Where slope reshaping involved hardpan disturbance, reactive tailings were carried and disposed in a safer location on the site.

Tmw99 Ettner, D.C.; Brasstad, G. (1999) Induced hardpan formation in a historic tailings impoundment, Roros, Norway. pg. 457.

Abstract: Historic sulfide mines at Roros, Norway, are protected from surficial disturbance by a conservation plan. Therefore, traditional remediation methods to reduce acid rock drainage at these mines would alter the landscape, and can not be implemented. An alternative remediation method to provide a subsurface chemical barrier by inducing hardpan formation with limestone/lime amendments has been tested at the Storwartz tailings impoundment. After one year, hardpan layers composed of sulfates and iron oxyhydroxides were observed. The hardpan layers significantly reduced the saturated hydraulic conductivity of the tailings and pore gas studies showed lower oxygen concentrations in shallow tailings. This field test showed that an indued hardpan can be formed at shallow depths in deeply oxidized tailings, and under extreme climatic conditions. The hardpan would function as a chemical barrier to reduce ARD and would allow the historical landscape to be kept intact.

Shay, D.A.; Cellan, R.R. (2000) Acid remediation at Homestake's Santa Fe Mine using a chemical cap. Proc. 2000 Billings Land Reclamation Symposium, March 20-24, Billings, MT. CD-ROM

Abstract: The Santa Fe Mine, located in west central Nevada, began leaching ore in 1988 and completed ore processing in 1995. Homestake Mining Company has completed final reclamation of the site, including remediation of waste dump acid conditions resulting from the oxidation of near-surface sulfide minerals. The production of acidity and the migration of acidity into cover soil became a significant detriment to previous revegetation success at the site. Acid geochemical conditions at the site indicated that the actual production and concentrations of acidity were relatively low, the result of low moisture regime, low biological activity, and limited oxidation of ferric ions. The oxidation of sulfides was a near-surface condition and the spread of acidity into cover soil materials was largely the result of

chemical diffusion processes. After examining several remediation options, Homestake elected to construct a chemical cap on the waste dumps to prevent the diffusion of acidity into new cover soil materials. Monitoring data from the site has indicated that the chemical cap has been successful in preventing the diffusion of acidity into cover soil materials and the long-term goal of revegetation success is likely.

Additional Notes: semi-arid climate, waste rock, cap purpose to neutralize existing near surface acidity and block diffusion of acid solutes. 20 t/ac magnesite and brucite applied uniformly over the surface, covered w/ 8-12" topsoil, cost of grading, purchase, hauling, application, revegetation, & engineering = $776,000

A2.7. Organic

A COMPARISON OF ORGANIC AND INORGANIC COVERS FOR LONG TERM PREVENTION OR AMELIORATION OF ACID MINE DRAINAGE.
Stogran, S.W.; Wiseman, M.E.
Sud95, V2, pg 555 (1995)

Abstract: An investigation into the potential for organic and inorganic covers to ameliorate acid Mine drainage processes is being conducted. This investigation includes a detailed characterization of several potential organic covers, in an effort to understand the complex chemistry of the covers. Column and pilot scale research is being conducted to evaluate the interaction between tailings and the organic cover materials. The cover materials being investigated include peat, compost, alkaline stabilized sewage sludge, and desulfurized slimes. The role of bacteria and bacterial requirements, and hydrogeologic and capillary factors affecting the prevention of acid Mine drainage is also being evaluated in large, pilot scale, laboratory cell simulations. Computer modeling was performed to assist in the design of the pilot cells and aid in the extrapolation of the data to field conditions. Through the understanding of the physical, chemical, and biological properties and processes, it is anticipated that sufficient data will be acquired to allow the design and evaluation of covers without extensive field testing. Limited field testing programs may still be required to confirm the pilot results.

EVALUATION OF SINGLE LAYER ORGANIC AND INORGANIC COVER MATERIALS FOR OXIDIZED TAILINGS.
Elliott, L.C.M.; Liu, L.; Stogran, S.W.
Tmw97, pg 247 (1997)

Summary Three different organic materials (peat, lime stabilized sewage sludge and municipal solid waste compost) were evaluated in a combination of bench and pilot scale lab test programs. A fourth non-organic material, desulfurized tailings, was also tested to provide comparative data. The organic cover materials tested demonstrate that there are significant differences in the ability of each material to provide a beneficial tailings cover. The results to date from the test program show that, of all the materials tested, the LSSS performed best meeting the objectives of a good tailings cover. The DST cover also showed promise with some modification to the single layer approach. The following paper summarizes the results of bench scale tests and a one year pilot scale test program designed to evaluate the effectiveness of organic cover materials at reducing acid generation.

APPLICATIONS OF METHODS FOR DELAYING THE ONSET OF ACIDIC DRAINAGE.
Delaney, T.; Hockley, D.; Sollner, D.
Van97, V2, pg 705 (1997)

Summary

Covering tailings and waste rock with organic material has been proposed as a method of controlling oxygen penetration into wastes. In addition to decreasing the amount of infiltration into the waste, organic covers can act as oxygen barriers in two ways: by maintaining a layer of saturated material on top of the waste which physically limits the downward movement of oxygen; and by consuming oxygen through the decomposition of organic material. Most organic covers involve both of these mechanisms.

The types of organic matter that have been examined for use as covers include municipal solid waste compost, forest industry waste, food industry waste, and peat. All of these materials can hold water in pore spaces. When saturated they act as a barrier to the movement of oxygen into the underlying waste. The amount of water retained by each material varies with the type of material and the amount of pore space.

A cover that is used to consume oxygen before it enters the underlying waste rock does so by decomposition. Depending on the rate of decomposition, this may greatly reduce the life of the cover. Therefore, if a cover is designed as a permanent solution, the cover material must be self sustaining in order to remain saturated and not decompose too quickly.

Whether the purpose of an organic cover is blocking or consuming oxygen, the cover must remain moist to saturated. Therefore, use of these covers are limited to areas with moderate to high rainfall conditions throughout the year. Recent applications are presented.

ORGANIC COVER MATERIALS FOR TAILINGS: DO THEY MEET THE REQUIREMENTS OF AN EFFECTIVE LONG TERM COVER?
Elliott, L.C.M.; Liu, L.; Stogran, S.W.
Van97, V2, pg 811 (1997)

Summary

This paper summarizes th results of bench scale tests and a one year pilot scale test program designed to evaluate the effectiveness of organic cover materials at reducing acid generation. To determine the effectiveness of organic covers and the processes involved, three different organic materials (peat, lime stabilized sewage sludge, and municipal solid waste compost) were evaluated in a combination of bench and pilot scale lab test programs. A fourth non-organic material. desulfurized tailings, was also tested to provide comparative data.

The organic cover materials tested demonstrated that there are significant differences in the ability of each material to provide a beneficial tailings cover. The results to date from the test program show that, of all the materials tested, the LSSS performed the best. The effluent pH increased from 3.5 to 6.1 after one year. Oxygen concentrations beneath the covers decreased to approx. 1% for all four covers. The DST cover also showed promise with some modification to the single layer approach.

A STUDY OF ACID MINE DRAINAGE CONTROL BY ADDITION OF A ALKALINE MILL PAPER WASTE.
Chtaini, A.; Bellaloui, A.; Ballivy, G.; Narasiah, S.; Lalancette, J.; Bilodeau, C.
Van97, V3, pg. 1147 (1997)

Abstract: A great deal of research effort has been undertaken to find an effective solution to the problem of acid Mine drainage. Indeed, Canadian legislation requires mining companies to respect environmental regulations by providing a rehabilitation plan with a financial guarantee. In order that the Canadian mining industry remains competitive, the proposed solutions have to be not only efficient but also economic, that is why the use of another waste material is attractive. The leaching tests undertaken in the laboratory show the efficiency of the combination of superimposition and incorporation of the alkaline mill paper waste. In fact, it can be observed that there is an important reduction of high toxicity elements, especially the heavy metals that are produced by metallic sulfur oxidation. In order to verify in-situ7 laboratory test results obtained for the control of AMD using alkaline mill paper waste, five demonstration cells were built on the Ascot Mine site. A monitoring program was followed to record temperature, leachate water quality and oxygen concentration. Monitoring results show that mixing Mine residues with alkaline paper mill waste and covering Mine residues with paper mill waste allows an efficient control of acid Mine drainage. The mill paper waste cover reduces oxygen diffusion rate and generates an alkaline front which gives a metal precipitation as hydroxides.

ORGANIC-WASTE COVER OVER THE EAST SULLIVAN MINE TAILINGS: BEYOND THE OXYGEN BARRIER.

Tasse, N.; Germain, D.; Dufour, C.; Tremblay, R.

Van97, V4, pg 1627 (1997)

Summary Covers used to control acid Mine drainage are intended essentially to stop acid producing Mine wastes from contact with oxygen. In the case of an organic cover, atmospheric oxygen is consumed by carbon oxidation before it reaches the problem causing sulfides. The practicality of the concept is well demonstrated by the ligneous covering of the East Sullivan Mine tailings, where forestry wastes, laid down since the mid-80's, cover almost 75% of the 136 ha tailings impoundment (end of 1996).

Plot	Organic Cover	Tailings
0	none	weathered
1	none	fresh
2	1 m bark	weathered
3	1 m bark	fresh
4	2 m bark	weathered
5	1 m bark and 30 cm sewage sludge	weathered

This paper summarizes the major characteristics of the tailings pile and of its wood waste cover, reviews and integrates data regarding how the cover presently functions, and presents a strategy by which such an organic cover could also be used to treat contaminated solutions generated before cover placement.

Field studies at East Sullivan have demonstrated that a 1 m wood waste cover can lead to full anaerobic conditions (O_2 < 3-5%), with methanogenesis (CO_2 20-30% and CH_4 10--40%) The decomposition of the barrier results in a marked increase in the alkalinity of the underlying groundwater (pH > 5.5-6, > 2000 ppm $CaCO_3$), and it constitutes a large reservoir of organic compounds which drive redox reactions. Absence of oxygen and interruption of sulfide oxidation, however, does not mean an immediate cessation of AMD. Oxidation prior to restoration has released acid and acidity to pore waters, and that acid prone water must be first purged from the tailings pile before the positive effects of alteration control can be observed. At East Sullivan, hydrogeologic modeling indicates that the production of acidic discharge could continue for 5 to 10 years after cover completion. Conceptually, the organic cover could be used for the treatment of the residual water

during that transition period, by simple recirculation through it. Thanks to its alkalinity and organic composition, it could assume the same function than passive treatment devices such as anoxic limestone beds and reducing wetlands. Organic covers, such as forestry wastes, have therefore a specific attraction, compared to other types of covers, in that they can assume a double role: that of an oxygen barrier, and that of an alkaline and reducing system, for the interim treatment of residual, acid-producing , waters.

LONG TERM EFFICIENCY OF WOOD WASTE COVERS: INDICATIONS FROM PORE GAS COMPOSITIONS.
Tasse, N.
Sud99, V2, pg 655 (1999)

Abstract: Prevention of acid Mine drainage basically involves interruption of sulfide oxidation. Reactive barriers, which consume oxygen, are prospective though unconventional alternatives to physical barriers. However, a reactive barrier implies, by definition, a problem of duration. Composition of pore gasses (O_2, CO_2, CH_4) was thus determined in several wood waste piles in order to decipher what would control the effective life span of a cover built with such a material.

As expected, oxygen consumption is less efficient in old wood wastes than in recent ones, and sawdust is definitively less reactive than bark. However, water saturation seems to be of prime importance: well-drained piles are much less efficient than those with a water saturated bottom. Methane testifies that full anaerobic conditions can be met. Significant occurrences (>10%) are limited to sites with water saturated bottom.

The long term efficiency of a wood waste cover seems to strongly depend on the water saturation that can be reached and maintained at the bottom of the pile. It is inferred that the build-up of a microbial bio-mass in a saturated or nearly saturated anaerobic environment helps to keep the amounts of nutriments and readily metabolizable organic substrates at a high level, which favors oxygen consumption.

A2.8. Self-healing/self-sealing Cover Systems

PRELIMINARY RESULTS OF A FIELD STUDY OF A SELF-SEALING/SELF-HEALING COVER SYSTEM.
McGregor, R.G.; Stegemann, J.A.; van der Sloot, H.A.
Van97, V3, pg 1435 (1997)

Summary: A field investigation of a self-sealing/self-healing barrier was undertaken at the East Mine tailings impoundment, near Sudbury, ON. The 100 m^2 field plot was constructed to evaluate the barrier's effectiveness at limiting the diffusion of atmospheric oxygen into the underlying tailings as well as determining the hydraulic resistance provided by the barrier to infiltrating pore water. Pore gas oxygen measurements within the vadose zone of the tailings revealed a marked decrease in O_2 concentration below the barrier (<3.4%) when compared to the O_2 profile of the shallow tailings beside the barrier test plot. Pore gas measurements also determined an accumulation of pore gas CO_2, of up to 17% of the pore gas, below the barrier. The calculated diffusivity of the pore gas oxygen through the barrier is less than 1/1000 that of the overlying tailings. Testing of cores taken through the barrier determined an average vertical K of 3.6×10^{-8} cm/s for the barrier compared to an average K of 3.9×10^{-4} cm/s for the surrounding tailings. Measurements for moisture content and porosity indicate

that pore water is being retained by the barrier in the overlying tailings. Preliminary field data indicate that the self-sealing/self-healing barrier is retarding pore gas diffusion as well as groundwater flow within the shallow tailings. Estimated cost: $30-50k/ha.

Installation: 75 cm over 100 m^2 was excavated and refilled with 26-30 cm reactive waste, the self-sealing/self-healing barrier, 17-23 cm high Fe-s material and filled to the top with the original oxidized tailings that had been excavated.

"Self-sealing/self-healing barrier" based on micro-scale properties of diffusion and chemical reactions. The process begins with the reaction of dissolved compounds to form a precipitate at the interface between two materials. Precipitation reactions at the interface result in a decrease in the aqueous concentrations of the reactive components and thereby create a concentration gradient. This gradient leads to diffusion of additional reagents to the interface, thus resulting in further precipitation until the pores between the two parent materials are completely filled. If the barrier is damaged the remaining parent materials will once again react at the new interface and restart the self-healing process, leading ultimately to a new barrier between the two parent materials.

A2.9. Soils

MINIMIZATION OF INFILTRATION INTO MINING STOCKPILES USING LOW PERMEABILITY COVERS
Udoh, F.D.
PhD thesis (1993)
#2866

Summary: This thesis presents a methodological evaluation of techniques used to limit water infiltration into mining stockpiles near Dunka Mine. The methodology employed involves initially screening a large number of materials for use as a potential stockpile cap. Selection criteria included availability, cost, workability, expected hydraulic conductivity, and any potential environmental problems which could result from the use of that material. By using HELP, analysis of various capping designs was conducted to determine the effectiveness of the selected cover systems to stem infiltration. Model results indicated that the major water loss occurred through evapotranspiration, and the single most important design parameter was the hydraulic conductivity of the barrier layer.

Based on model results and the most cost effect design alternatives, a field test was conducted to evaluate the effectiveness of various capping alternatives in reducing drainage from mining stockpiles. Four barrier materials were installed: glacial till screened to -2.5" (1), glacial till screened to 0.5" (2), glacial till screened to -2.5" mixed w/ 5% bentonite (4), and a 20 mil PVC liner (3). Although all the test plots significantly reduced the amount of contaminated bottom flow from a stockpile, 2 (83%), 3 (79%), and 4 (88-97%) produced much less bottom flow than 1 (60%).

Construction:
1. 12" compacted -2.5" glacial till
2. 12" compacted -0.5" glacial till
3. 20 mil PVC membrane; 6" pit run sand
4. 5% bentonite and -2.5" glacial till constructed in two 6" lifts = 12" total

Table 6: Cost Estimates

Standard Reclamation (2' cover)	$0.55 million/90 acres

Compacted till	$0.90
Compacted till (-2") + 5% bentonite	$2.00
Compacted till, screened (-2-1/2") + 5% bentonite	$2.20
20 mil PVC	$1.30
30 mil PVC	$1.40
40 mil PVC	$2.20

THE INCLUSION OF BIOINTRUSION CONSIDERATIONS IN THE DESIGN OF THE RECLAMATION COVER FOR THE DMC TAILINGS IMPOUNDMENTS
McLendon, T.; Colman, J.; Shepard, T.A.; Nelson, R.E.
Tmw97 pg 267 (1997)

Summary: The initial design of the reclamation cover for the U tailings impoundments incorporated a typical multi-layer system to provide long-term radon emanation control and ground water protection. During the design evaluation process, the issue of biointrusion as a potential mechanism for cover failure wrt these two basic performance criteria was raised. In response, DMC redesigned the cover based on ecological principals relating to vegetation dynamics to remove the concern for biointrusion. The multi-layer cover was replaced with a thick homogeneous cover of sandy site soils. Performance of the reclamation cover with respect to ground water protection was evaluated by the application of a detailed water balance.

APPLICATION OF ARD ABATEMENT TECHNOLOGY IN RECLAMATION OF TAILING PONDS AT COMINCO LTD., SULLIVAN MINE
Gardiner, R.T.; Dawson, B.B.; Gibson, G.G.
Van97 V1 pg 47 (1997)

Summary: The Sullivan Mine, BC will close in 2001 after 90 yrs of continuous operation. During that period some 90 mt of reactive tailing containing pyrrhotite and pyrite were placed in ponds that cover 373 hectares of land. Tailing effluent and contaminated seepage and groundwater have been collected and treated with lime in a high density sludge process for nearly two decades. Reclamation of the tailings ponds will incorporate a combination of ARD abatement technologies including continuing operation of the collection and treatment system and application of a soil cover system. The purpose of the soil cover, which will be constructed of locally available concentrator by-product and glacial till, is to reduce volume of tailing seepage requiring treatment by limiting precipitation infiltration and to provide a growth medium capable of sustaining vegetation that achieves land use and productivity objectives.

Quantities of suitable soil for cover construction within an affordable haul distance are limited. Selection of the soil cover system (20-60 cm float rock, 20-60 cm float rock and 45 cm till, 20-60 cm float rock and 25 cm compacted till and 30 cm non-compacted till, 20-60 cm float rock and 25 cm compacted till and 15 cm float rock and 30 cm non-compacted till) for tailing pond reclamation is based on a combination of factors including in situ performance of test covers, predictive modeling using SoilCover.

Due to the extensive area of land occupied by tailings ponds, estimated cost to construct a soil cover system (#2: float rock and till?) that achieves ARD abatement ad reclamation objectives is $15 million ($4.00/m^2). Increasing the complexity of the soil cover by incorporating a compacted till layer reduced precipitation infiltration to low levels, however, the expected benefits of lower water treatment costs and reduced security deposit were insignificant in

comparison to the increased cost to construct the more complex soil cover.

FIRST YEAR FINDINGS FROM SOIL COVER TEST PLOTS ON KIDD CREEK THICKENED TAILINGS NEAR TIMMINS, ONTARIO
Woyshner, M.R.; Swarbrick, B
Van97, V3 pg 1075 (1997)

Summary: The Kidd Creek thickened tailings impoundment is unique by having a very high degree of saturation at shallow depths, even where the watertable is several meters deep (beneficial for limiting oxidation). Evaporation from the tailings surface is the principal dewatering mechanism. It lowers the degree of saturation at the surface which results in enhanced oxidation rates. In order to retain a high degree of saturation a storage-and-release soil cover was proposed, whereby rainfall is stored in the cover and then used for evaporation.

Three test plots were constructed on the tailings where the water table was at max depth: one composed of 60 cm nonreactive beach tailings; another constructed of 45 cm nonreactive underlain by 15 cm slag, the third of 60 cm clay. The covers were monitored for one year, measuring pore gas oxygen and soil moisture content, soil suction and percolation through the cover.

Findings showed that the covers responded as a storage-and-release system for water but were ineffective as oxygen barrier. Calculated oxidation rates beneath the covers were 10 to 40 times less than the present rates. Oxygen flux was reduced from 729 mol/m^2/yr to 36 (nonreactive tailings), 74 (nrt and slag), and 13 (clay).

Method: Previous work included field and lab tests of the hydraulic and geotechnical characteristics of the tailings (Barbour et al., 1993) and also a water balance study pointing our the importance of summer evaporation (Woyshner and St-Arnaud, 1994; Al and Blowes, 1995).

This paper dealt with the experimental test plots:
pore gas O_2 - probes
moisture content - TDR
hydraulic head - piezometers
hydraulic conductivity - air entry permeameter methods
percolation - lysimeters

TAILINGS IMPOUNDMENT RECLAMATION SOIL COVER DESIGN AT THE RIDGEWAY MINE.
Kowalewski, P.E.; Dorey, R.; Wilson, G.W.; Duckett, R.
Tmw98 pg 369 (1998)

Summary: A reclamation soil cover needed to be designed for the 300-acre gold tailings impoundment at the Kennecott Ridgeway Mine, SC. A methodology combining the use of the SEEP/W and SoilCover models was used to evaluate potential soil cover configurations with respect to infiltration into the underlying tailings. The objective of the reclamation soil cover was to isolate the tailings from the environment and minimize oxygen flux into the tailings.

Three different potential soil cover configurations were evaluated for construction at the Ridgeway site. In addition, two different construction methods: slurrying or physical placement of cover materials were evaluated. Based on the combination of the results of the modeling, cover constructability, and construction cost, a cover consisting of 36" saprolite

and 7" topsoil and vegetation over the tailings mass was considered to be the best alternative for limiting percolation, while maintaining a saturated tailings mass.

SOIL COVERS FOR SLOPED SURFACES OF MINE WASTE ROCK AND TAILINGS
Boldt-Leppin, B.; O'Kane, M.; Haug, M.D.
Tmw99 pg 393

Abstract: A literature search of soil cover design principles and applications demonstrated that the design and monitoring of these cover systems was completed with respect to the horizontal or top of the waste rock piles. The influence of the sloped surfaces on hydraulic performance of the cover system was either ignored or the slopes were covered with impermeable geomembranes in order to avoid infiltration or exfiltration across the protective soil cover. This paper summarizes the literature search and presents key design principles. The analogy to hill slope hydrology is proven. Case studies are presented to demonstrate current state-of-the-art technology.

ALLIGATOR RIDGE TAILINGS IMPOUNDMENT CLOSURE: A 100 YR PERFORMANCE OF A SOIL COVER
Newman, L.L.; Wilson, G.W.; Reed, M.F.
Tmw99, pg 417

Abstract: Predicting the flow of water between the ground surface and the atmosphere is a critical issue in the design of soil covers. both short-term and long-term net infiltration rates are required to ensure that effluent stored within the tailings as well as precipitating water does not release constituents into the surrounding environment. The soil cover at Alligator Ridge was designed by characterizing the tailings and cover materials and by using the numerical model SoilCover. The results indicate that a net upward flux develops within the soil cover profile due to a moisture deficit in the system. The result of a 100 year simulation showed that after approximately 15 to 20 years of successive evaporation, the reduced water contents in the profile affected the ability of the tailings to transport moisture to the surface for evaporation. Subsequent movement of water within the tailings was primarily a result of vapor flow.

APPENDIX 3

Annotated Bibliography of References
Physical Containment of Reactive Mine Wastes
Underwater Disposal

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A3.1. General

WASTE ROCK LEACH TESTS AT THE CLUFF MINING OPERATION IN NORTHERN SASKATCHEWAN
Quarshie, L.; Rowson, J.
Sud95, V1, pg 217

Abstract: The Cluff operation designed, installed and operated three industrial scale waste rock leaching tests. Actual mined waste rock from the existing Dominique-Janine north waste rock pile was tested. The intent was to dispose of the fresh mined rock underwater in Cluff Lake.

Three experimental leach tests were operated from November 1992. The objective was to compare the degree of leachability in each of the three tests with respect to contaminant release over time. The three tests were as follows; i) Dynamic test- was designed to provide data from simulation of the leaching of submerged waste rock using fresh water from Cluff Lake, ii) Static test was designed to provide water quality data from submerged waste rock after mining operations, iii) heap leach was designed to proved, as a comparison, water quality data from above ground storage of waste rock.

All three tests operated successfully, generating consistent, reliable data. It has been quantitatively demonstrated that submerged waste rock is much less chemically active than surface stored waste rock.

A PREDICTIVE QUANTITATIVE GEOCHEMICAL ASSESSMENT OF THE SUBAQUEOUS STABILITY OF ACID-GENERATING MINE TAILINGS
Mugo, R.K.; McDonald, D.; Riehm, D.; Napier, W.A.
Van97, V1, pg 237

Abstract: The geochemical stability of sulfide-rich tailings from the Voisey's Bay Ni-Cu-Co Project in Labrador, Canada was tested in laboratory experiments in which tailings were overlain by both fresh and sea water covers. Tailings reactivity was assessed using two different approaches: 1) monitoring of temporal trends in metals concentrations and fluxes in the water cover and 2) assessment of tailings pore water chemistry using dialysis array membrane samplers (peepers). Both the water column and peeper data suggest that the long-term reactivity of Voisey's Bay tailings is reduced as a result of storage under subaqueous conditions.

Water column leach tests indicate an initial quick release of metals (Ni, Co, Zn) into the water column likely produced by swift dissolution of either the more soluble tailings minerals or of altered particle (i.e. oxidized) surfaces. Following this initial quick release (0-30 days), a much slower steady-state release of metals is observed (up to 200 days). The latter process likely reflects a combination of post-depositional alteration of tailings coupled with a reduction in exposed particle surface area. Under seawater cover, the longer-term flux of metals and acid generation are lower likely as a result of enhanced buffering and neutralization from the higher alkalinity levels.

Peeper results of metal concentrations in tailings pore waters are in agreement with leach test data with respect to the long term stability of Voisey's Bay tailings under subaqueous conditions. Concentrations of the key metals Ni, Co, Cu and Zn are all markedly lower (and in some cases near or below the detection limit) in tailings interstitial waters compared to the

water column. These results suggest that the submerged tailings are undergoing only minimal reactivity and that metals are not being leached to pore waters. As a result, the tailings are unlikely to support a diffusive efflux of metals into the overlying water column.

Taken together, these data suggest that subaqueous disposal of Voisey's Bay tailings is feasible and offers the potential to inhibit tailings reactivity, unlike the case for many terrestrial tailings impoundments.

WATER COVER ON REACTIVE TAILINGS AND WASTEROCK: LABORATORY STUDIES OF OXIDATION AND METAL RELEASE CHARACTERISTICS
Dave, N.K.; Lim, T.P.; Horne, D.; Boucher, Y.; Stuparyk, R.
Van97, V1, pg 779

Abstract: Laboratory column lysimeters studies were undertaken to evaluate the oxygen diffusion and metal release characteristics of underwater deposited reactive tailings and waste rock. The experiments were conducted for un-oxidized tailings consisting of un-classified, fine and pyrrhotite tailings, and partially oxidized and weathered tailings and waste rock from base metal and gold mining operations. The test were conducted in 0.3 m x 0.3 m x 2 m high clear acrylic columns, using natural lake water for cover with two water cover depths of 0.5 and 1.0 m, both under un-circulated and circulated water column conditions. In another experimental arrangement, the reactive tailings were covered, at the waste-water interface, with an additional layer of low sulfur tailings or an organic layer comprised of low grade municipal compost.

The oxygen diffusion results showed that dissolved oxygen in the interstitial water was rapidly depleted in the waste material, within the first 10 cm of the interface, irrespective of its nature, and was limited only by the low oxygen diffusion and solubility in water. In tailings covered with the organic compost or low sulfur tailings at the waste-water interface, the dissolved oxygen was consumed by these covers and oxygen ingress in the waste material was prevented.

The results for oxidation and leaching studies indicated that surface oxidation of the waste material was slowly occurring at the interface in all columns except in those where an additional layer covered the waste. The organic cover layer over the waste consumed oxygen, and prevented upward migration of contaminants from previously weathered and oxidized waste. The low sulfur tailings cover also attenuated the migration of high acidity and metals from the oxidized waste below, but the oxidation of the cover tailings at the surface released some nickel to the water cover.

SUBAQUEOUS DEPOSITION OF ACID GENERATING TAILINGS INTO AN ACIDIC ENVIRONMENT; PILOT COLUMN TEST RESULTS
Stogran, S.W.; Elliott, L.C.M.; Liu, L.
Van97, V3, pg 1059

Abstract: The subaqueous deposition of tailings is considered to be one of the most promising methods of reducing or eliminating acidic drainage from tailings. One of the concerns of subaqueous deposition has been the potential of metals leaching into the cover waters and, therefore, increasing the metal concentrations in the water to above the acceptable limits. This increase in metal concentration may be greater when the tailings are deposited under acidic water. This project was conducted to determine if the generation of acid and metal leachates was affected by the use of acidic water as covers for subaqueously deposited tailings.

Bacteriological analyses were also conducted of water samples to determine what biota would be present in the system.

The following paper summarizes the results of subaqueous tailings pilot column test work conducted to determine the effects of subaqueously deposited tailings on water covers and tailings pore water. Two types of tailings were tested: high sulfide tailings (pyrrhotite tailings), and low sulfide tailings (end of pipe slime tailings). Five pilot columns were constructed and filled with different tailings combinations. The tailings were covered with a 1 m thickness of acidic surface water and data was collected from five columns over a 13 month test period. The results indicated that a stagnant 1000 mm water cover was capable of maintaining the underlying tailings in a reducing condition. The upwards diffusion of pore water resulted in a pH increase in the waters overlying the thickened pyrrhotite tailings and the pyrrhotite tailings with a shallow cover of substrate. A conductivity gradient between the tailings and the water cover caused a diffusion of salts upwards into the overlying water column. Precipitation noted at the tailings water interface may be related to the precipitation of ferric oxyhydroxides, which resulted in a decrease in Fe concentrations noted in the water cover. Other metal concentrations did not exhibit significant increases in the water cover. A sulfate concentration gradient between the tailings and the water cover may have caused the diffusion of sulfate from the tailings into the water cover. Results of the bacteriological analysis conducted during the program showed the presence of a fungal growth in the columns.

EVALUATING CLOSE-OUT OPTIONS FOR ACID GENERATING TAILINGS
Jones, D.R.; Ellerbroek, D.A.; Laszczyk, H.
Van97, V3, pg 1303

Abstract: A major study designed to evaluate close-out options for three sulfide-rich tailings impoundments has been initiated by the CSIRO Minesite Rehabilitation Research Program and Renison Ltd at the Renison Bell Mine in southwest Tasmania. The sulfides, primarily in the form of pyrrhotite, contain only low concentrations of other metals which means that acidity and concentrations of other metals which means that acidity and concentrations of dissolved iron are the primary water quality issues.

The major objective of the work program is to evaluate options for preventing oxidation of sulfides in the tailings and for minimizing future production of acidic surface runoff and poor quality seepage. One option being considered is a wet cover to minimize oxygen diffusion into the tailings. This strategy may be supplemented by creating a wetland on top of the final landform. The wetland would treat surface runoff in situ and would further limit penetration of oxygen into the underlying tailings by creating an organic-rich anaerobic surface layer.

A positive year round water balance is a fundamental requirement for a wet cover. Consequently, considerable effort has been devoted to water balance modeling during the first year of the project. This has proceeded in parallel with unsaturated flow modeling to determine the saturation characteristics of the proposed cover material. Piezometric data indicate that strong downward hydraulic gradients exist within the tailings impoundments. The pH of porewaters is approximately 5.8 and the water chemistry is dominated by calcium, sulfate, and iron. All of the iron is present in the ferrous form. Saturation index calculations indicate equilibrium with respect to gypsum but undersaturation with respect to ferrous iron phases.

SUBAQUEOUS TAILINGS DISPOSAL IN FRESHWATER AND MARINE ENVIRONMENTS - RESULTS OF PREDICTIVE GEOCHEMICAL TESTING USING TAILINGS WITH DIFFERENT COMPOSITIONS

Mugo, R.K.; McDonald, D.; Poling, G.W.

Sud99, V1, pg 99

Abstract: The disposal of reactive mine tailings in an environmentally sound yet cost-effective manner is an issue of concern facing the mining industry worldwide. In particular, sulfide-rich tailings pose the greatest risk due to their potential to generate acid rock drainage and concomitant release of metals to the environment. Subaqueous tailings disposal (STD) is considered an attractive option both from an environmental (the water cover reduces the influx of dissolved oxygen to tailings and hence retards or slows oxidation and metals release) and economic (little maintenance and ongoing support required, allowing for a near "walk away" solution) perspective. Some of the negative impacts resulting from STD include temporary alteration of benthic habitats.

Over the last few years, we have been carrying out laboratory tests on tailings with different geochemical properties in order to predict their likely short and long term behavior once disposed of in the natural environment under either fresh water or seawater covers. Our approach involves measurement of contaminant concentrations in overlying waters and in tailings pore waters, to determine the magnitude and direction of concentration gradients, and hence, metal fluxes from the tailings. Additionally tailings are subjected to mineralogical tests in order to identify potentially reactive metal-bearing mineral phases, and also visible signs of tailings alteration resulting from underwater storage. The data gathered so far suggest that the reactivity of tailings with vastly different geochemical and mineralogical properties is reduced by storage under water, in contrast to tailings stored subaerially. This paper presents laboratory results of the reactivity of tailings from three different mining projects. Using these results, we examine the factors responsible for tailings geochemical behavior under water covers, and in particular the likely long term stability of the tailings once disposed of in the natural environment.

ASSESSMENT OF WATER QUALITY ASSOCIATED WITH UNDERWATER DISPOSAL OF TAILINGS AND WASTE ROCK FROM THE VOISEY'S BAY PROJECT, LABRADOR, CANADA

Nicholson, R.V.; Rinker, M.J.; Williams, G.

Sud99, V1, pg 127

Abstract: A laboratory test program was conducted to assess underwater disposal of potentially reactive tailings and waste rock associated with the proposed Voisey's Bay mine-mill project in Labrador, Canada. Representative samples of tailings and mine rock were placed in flooded columns and were sampled over 6 to 20 months. The tests were designed to monitor the chemical composition of pore water within the waste and the overlying water column. The flux of potential contaminants from the waste into the water column was also assessed to provide data to model future lake-disposal scenarios.

The results showed that sulfate is a good indicator of oxidation reactions and that nickel was the only metal of potential concern for environmental impact during underwater disposal. Waste rock exhibited lower sulfate fluxes but higher nickel fluxes to the water column than did tailings. The water column above the waste rock did not exhibit any net acid loading over a 20 month period as a result of net alkalinity released from the non-sulfide portion of solids in the rock. The presence of a thin layer of peat (0.1 m) over the tailings resulted in decreasing sulfate and metal concentration and neutral buffered pH in the water column as a

result of sulfate reduction. Nickel release to the water column occurred under neutral pH conditions. Concentrations of nickel appear to be controlled, to some degree, by pH but only for values above 7.5 to 8.0.

Preliminary modeling of sulfate release from waste rock suggest that peak concentrations in the water column will occur over periods of 2 to 4 years with monatomic declines thereafter. Similar behavior for nickel concentrations is anticipated. This implies that although water quality in the lake may not be acceptable for discharge immediately after disposal ceases, concentrations will decline with time. Monitoring will be required to determine whether or not additional mitigative measure such as barriers (inert or other layers such as peat) may be required for decommissioning.

A3.2. Flooding Tailings Basins

CONSIDERATIONS IN THE USE OF SHALLOW WATER COVERS FOR DECOMMISSIONING REACTIVE TAILINGS

Li, M.G.; Aube, B.; St-Arnaud, L.

Van97, V1, pg 115

Abstract: Shallow water covers in engineered containment structures are becoming increasingly accepted as state-of-the-art for decommissioning of mine waste disposal sites. However, the benefits of water covers are site-specific. The shallow water cover system is a complex combination of physical and chemical processes which take place simultaneously and interdependently. To predict the long-term performance of shallow water covers, these processes must be considered and the key processes modeled. This paper examines the processes and factors influencing underwater sulfide oxidation and ultimately the water cover quality. Mathematical modeling using the Louvicourt site as a test case shows that contributions of water cover aeration, downward infiltration, and tailings resuspension to total subaqueous sulfide oxidation are in the same order of magnitude. Each of these three oxygen transport mechanisms is able to increase subaqueous oxidation by an order of magnitude when compared with a stagnant water cover, where molecular diffusion is the only oxygen transport mechanism. a simulation based on conservative assumptions shows that the discharge water quality after mine closure could meet current federal discharge limits and that the shallow water cover could provide an acceptable long-term solution for reactive tailings disposal at this site.

FIELD STUDIES OF BIOLOGICALLY SUPPORTED WATER COVERS AT TWO NORANDA TAILINGS PONDS

St-Germain, P.; Larratt, H.; Prairie, R.

Van97, V1, pg 133

Abstract: Water covers for storage of pyritic mine residues are efficient at minimizing pyrite oxidation. The effectiveness of water covers can be improved by including a sediment layer which consumes oxygen through biological activity. In the resulting biologically supported water cover, maintenance of the sediment activity over time is ensured by a living plant cover. The feasibility of implementing a plant cover was assessed in the field at two Noranda sites.

The 80 ha Brenda Mine tailings pond is alkaline (pH 8.4) and water depths range from 1 to 6 m. In September 1992, 850 submerged "sandwich" units with a plant mix of 75% *Elodea*

canadensis, 15% *Potamogeton crispus* and 5% other species, were distributed in 1 to 4 m of water. Rooting took place within two weeks and rapid plant growth produced weed beds varying from 60 to100% cover by 1995. Conditions in the sediment were reducing and up to 10^6 cells of sulfate-reducing bacteria/g of surface sediment were detected.

In the fall of 1995, a pilot scale demonstration test was initiated in the 90 ac Heath Steele tailings pond. The pond was very alkaline with the pH maintained between 9.5 and 10.5. Most of the sediment was settled lime sludge and water depths were generally less than 2m. In total, 160 "sandwich" units covering an average area of 1300 m^2 were put into the pond. Poor plant growth and low phytoplankton: zooplankton ratios (<90%) suggested inhibition of photosynthesis. Maintenance of a pH lower than 9 is preferable for the establishment of a plant cover with submerged aquatic plants. As expected in a biologically inert pond, sediment conditions were not reducing and sediments were low in organic matter content.

SHALLOW WATER COVER DESIGN METHODOLOGY AND FIELD VERIFICATION
Atkins, R.J.; Hay, D.; Robertson, J.
Van97, V1, pg 211

Abstract: Shallow water covers are used to prevent and minimize acid production in acid generating tailings by placing the tailings under a layer of water. The concept of shallow water covers is to use as shallow a depth of water as possible thereby eliminating the necessity of impounding large volumes of water while still precluding the disruption of the physical structure of the bed by wave action. A study defining the physical variables associated with the design of adequate water cover was undertaken leading to a design logic chart illustrating how the design of a shallow water cover fit into the overall design of the tailings pond. The minimum depth of water required as a cover depends primarily on: i) the return period for the design wind event based on the projected life of the pond; ii) the size of waves generated by the design wind event; iii) the water depth to which the wind generated waves will mobilize tailings at the bed.

A general model to predict the depth at which wave mobilization of the bed is negligible was developed. Field verification of the general model was undertaken with data collected from the Equity Silver tailings pond, situated near Houston, British Colombia, Canada. The generalized model predicted that wave motion interaction with the bed would reach negligible levels around 1.4 m water depth for the maximum measured wind event since the cessation of operations. Observations of bedforms in the pond indicated that wave motion interaction with the bed ceases between 1.3 m and 1.4 m water depth. The correspondence between the two water depth values indicates confidence in the predictive model.

SULFIDE OXIDATION RELATED TO WATER TABLE DEPTH AT TWO SUDBURY, ONTARIO TAILINGS IMPOUNDMENTS OF DIFFERING PHYSIOGRAPHY
Robertson, W.D.; Blowes, D.W.; Hanton-Fong, C.J.
Van97, V2, pg 621

Abstract: Two tailings impoundments in close proximity but with different physiography, and containing similar sand and silt-sized tailings from adjacent Ni-Cu ore bodies in the Sudbury Basin, were evaluated to assess propensity for sulfide oxidation. At the Strathcona site (subaqueous) tailings has been deposited into a lake basin over a 27 year period so that most of the tailings has remained submerged and presently shows no evidence of post-depositional oxidation. However, because the spigotting point has remained fixed, and exposed beach

area has developed where sulfide oxidation appears to be occurring locally. Sulfate levels in the shallow water table zone of the beach area (up to 18,000 mg/L) are up to ten times higher than in the distal unoxidized porewater (~1800 mg/L). Presumably this reflects periodic desaturation of the beach area tailings as consequence of its elevation above lake level and as a result of the preferential deposition of the tailings coarse size fraction near the spigotting point. Highest sulfate levels occur in the shallowest beach area porewater indicating that desaturation and oxidation intensity are increasing as the beach is progressively elevated above lake level.

The Fecunis (subaerial) site, was decommissioned 20 years prior to the field study and contains tailings impounded within an elongated valley by a 18 m high rock-fill dam at the downgradient end. Because tailings spigotting occurred at the upgradient end of the valley, away from the dam, hydraulic sorting allowed the tailings fine size fraction to be preferentially deposited in the downgradient area near the dam. As a consequence, the tailings near the dam are of sufficiently low permeability that natural precipitation recharge is capable of maintaining relatively high water table levels (<2 m depth) at locations close to the dam. As a result, the amount of tailings susceptible to oxidation is less than would otherwise be the case at this site.

These examples highlight the importance of considering the effects of hydraulic segregation when mine tailings are discharged as high water content slurries. This effect can be used to advantage in maintaining high water table levels in near-dam areas that are normally prone to oxidation or may require that special precautions be undertaken to avoid unsaturated conditions near the spigotting points where the coarser material accumulates.

FLOODING AS A RECLAMATION SOLUTION TO AN ACIDIC TAILINGS POND: THE SOLBEC CASE

Amyot, G.; Vezina, S.

Van97, V2, pg 681

Abstract: The Solbec tailings pond was active from 1962 to 1977. Over 2.5M cubic meters of sulfide waste was deposited at the site, and sporadic sampling performed between 1972 and 1980 confirmed the presence of AMD. A 1987 characterization report of the tailings pond tabled proposed flooding of the tailings as the most appropriate solution to the problem. It was at this time that Cambior became involved through its acquisition of the Sullivan Group, owner of the Solbec mine.

A series of experiments and studies followed from 1989 to 1993 to test the efficiency and viability of the flooding as a solution. The work required to achieve flooding was carried out in 1994. Since then, as part of the MEND program, a project has been conducted to monitor the quality of the water cover and ground water associated with the tailings pond. The monitoring program also includes an elevation of the micro-organisms viability and level of activity in the flooded pond.

After seven sampling and analysis campaigns of over 50 samples and ten parameters each, the effectiveness of the solution is appearing. The pH is now near neutral and the anomalous concentrations of iron, zinc and copper are resorbing.

This trend is supported by a decrease in the oxidizing microbial population, the cessation of their oxidizing activity and, most notably, the appearance of sulfate-reducing bacteria. These bacteria contribute to the inverse oxidation process by reducing sulfate ions to sulfide ions, which reprecipitate the metals present in the more stable form of metal sulfides.

INTERIM ASSESSMENT OF FLOODED TAILINGS PERFORMANCE QUIRKE MINE WASTE MANAGEMENT AREA
Kam, S.N.; Knapp, R.A.; Balins, J.K.; Payne, R.A.
Van97, V2, pg 853

Abstract: This paper presents an interim assessment of the performance of the flooded Quire Mine Waste Management Area in Elliot Lake, Ontario following the completion of the decommissioning work in 1995. The Quirke Mine Water Management Area contains approximately 45 million tonnes of uranium tailings and waste rock impounded behind relatively impervious earth dams built around the perimeter to minimize seepage flows to the surrounding area.

The Elliot Lake uranium deposits have low uranium concentrations but contain about 5% pyrite. The decommissioning works have been designed to inhibit long-term acid generation and to minimize radiological releases from the facility. Various options to decommission the waste management area were investigated. It was concluded that complete submergence of the tailings would be the most cost effective method to minimize impacts on the environment in the long term. In order to achieve this a series of internal dykes were constructed and the tailings, in the individual cells, were then flooded. Surface drainage is routed through these cells via spillways provided on the dykes.

Construction of the internal dykes was carried out in stages from 1990 to 1995. The first of the internal cells (Cell 14) was flooded in 1992. Since that time a vigorous monitoring program has been in place to assess the hydrogeological and geochemical performance of flooded tailings scheme. The data collected to date confirms that the facility is performing well. Inter-cell seepage continues to play an important role in flushing the porewater out of the tailings. The surface water quality has improved over the monitoring period.

SUBAQUEOUS TAILING DISPOSAL; A SOUND SOLUTION FOR REACTIVE TAILING
Robertson, J.D.; Tremblay, G.A.; Fraser, W.W.
Van97, V3, pg 1027

Abstract: Subaqueous tailing disposal is the placement of tailing under a water barrier. This is proposed as an effective means of preventing the oxidation of the sulfide minerals and the subsequent release of trace metals. A research project has been conducted on subaqueous tailing disposal from 1988 as part of the Canadian MEND research program.

The project consisted of three major phases: preliminary studies to scope the effectiveness of subaqueous disposal at several sites, more detailed geochemical studies at two specific sites and finally development of design guidelines for an application guide. The majority of the work has been focused on addressing the critical concern of the potential for trace metals contained in the tailing pore water to leach into the overlying water column. A description is provided of the chemical mechanisms which act to create stable sediments which prevent leachates from diffusing from the tailing.

An information program was conducted for updating the various stakeholders on the study results as the project evolved. This was a critical step in obtaining preliminary qualified public and regulatory endorsement and for justifying the costs of additional phases of work. In addition two peer reviews were conducted at stages in the program to improve the methodology applied in the subsequent studies.

The overall cost to date for the subaqueous disposal program is $1,559,000. A total of 24 reports and/or scientific papers have been prepared on this project.

The peer reviews also reaffirmed that the application of this method to natural lakes required the acquisition of comprehensive biological information, much of which would be site specific, and which was not technically or financially feasible in this generic research project. consequently, the final design work is focusing specifically on the application of the results to future man-made tailings ponds and small headwater lakes. A generic design guide has been developed for applying this technology.

GEOCHEMICAL FIELD STUDY OF FLOODED MINE TAILINGS AT STEKENJOKK, NORTHERN SWEDEN

Ljungberg, J.; Lindvall, M; Holmstrom, H.; Ohlander, B.

Van97, V3, pg 1401

Abstract: The tailings at the Stekenjokk mine in northern Sweden have a strong acid producing capacity, and a decommissioning program based on flooding was completed 1991. Flooding was performed by raising the water level in the tailings and clarification pond. A geochemical field study of the efficiency of flooding to reduce sulfide oxidation was performed during 1995. The results are presented in this paper. the pond water is well mixed and oxic the whole year round, and has higher concentrations of Ca (20 ± 7 mg/L), S (11.1 ± 0.3 mg/L), Zn (139 ± 8 ug/L) and Cd (0.69 ± 0.07 ug/L) than local background values. cu-content is low (1.8 ± 0.3 ug/L). Pore waters have higher concentrations of Ca and S than the water column, but in general have lower or similar concentrations of Zn and Cd. Only in tailings which have been oxidized and weathered before the flooding, the pore water concentrations of Zn and Cd are much higher than those of the water column. Although this type of oxidized tailings covers only a small part of the tailings deposit, mixing calculations using Ca/1000Sr ratios suggest that 60% of the Ca in the water column originate by diffusion form pore water in these tailings. Dissolution of gypsum in the oxidized tailing is the most probable explanation to the high concentrations of Ca and S in this pore water. release from the parts of the tailings which have been oxidized before the flooding is probably also the most important source of Zn in the water column. Remnants of process-water in combination with iron sulfide oxidation and carbonate buffering control the pore water geochemistry in the uppermost part of the normal tailings at Stekenjokk. Oxidation of resuspended tailings in the pond water is not an important metal source to the water column. The breakwater system works well.

COMPARISON OF MODEL PREDICTED AND MEASURED COPPER AND ZINC CONCENTRATIONS AT THREE NORWEGIAN UNDERWATER TAILINGS DISPOSAL SITES.

Arnesen, R.T.; Bjerkeng, B.; Iversen, E.R.

Van97, V4, pg 1831

Abstract: Disposal of tailings from sulfide ore mines under water was introduced in Norway in 1968. Compared to more traditional methods of tailings disposal, this seemed to give small effects on water chemistry and on the biological situation in the recipient. Subaqueous disposal was therefore established at 7 different Norwegian mines in less than 10 years. To gather more information of the effects of such tailings disposal, the outlets from the deposits and the receiving waters were monitored at all these mine sites.

When mining activities were closed down, discussions of necessary measures and future

development concerning the tailings, resulted in a simple model for this calculation. Assuming that molecular diffusion of oxygen in the sediment is the rate determining step, the model calculates the liberation of pollutants. The model was originally developed for an inert cover, but later modified to handle uncovered tailings.

To illustrate the present and assumed future impact on water chemistry from subaqueous tailings deposits, data from three different Norwegian mine sites are presented. Two o these mines use tailings ponds for the disposal, while one started discharging tailings into a lake. Due to effects on biota in the receiving water, this lake was later converted to a pond.

Experience from Norwegian subaqueous deposits of tailings show that environmental effects from these tailings have been markedly less than those experienced with traditional methods of disposal. The method is not without environmental consequences, and it is necessary to maintain possible constructions for an indefinite period of time. The model developed at NIVA to estimate future development in water from such deposits has been tried on a number of Norwegian and Swedish tailings deposits. The examples discussed in this presentation shows that the results obtained gives results roughly in the right order of magnitude. Field data, laboratory tests, and model calculations indicate that leakage of copper from the subaqueous tailings will be small, while that of sulfate and zinc can become quite substantial.

DESIGN GUIDELINES AND STABILITY CRITERIA OF ENGINEERING WORKS FOR WATER COVERS

Aubertin, M.; Dionne, J.; Marcoux, L.

Van97, V4, pg 1849

Abstract: Water covers are sometimes considered as the most effective way to control acid mine drainage production. In recent years, they have been installed on a number of sites in Canada and elsewhere. Although this technique has some definite advantages, it also has some drawbacks. One of the main concerns is the long term stability of large man-made reservoirs. One has to take into account the extended life of such retaining structures and the hazards associated with possible failure of the system caused by flood or earthquake. These aspects have been considered by the Quebec Provincial Government which has recently proposed some design guidelines for closure and reclamation of mining sites. In this paper, the authors present some elements contained in these guidelines, which are also discussed in relation to approaches and parameters used elsewhere.

WET CLOSURE OF EXPOSED TAILINGS USING SURFICIAL LIME SLURRY APPLICATION

Evans, A. Jr.

Tmw99, pg 485

Abstract: The wet closure is a remediation technology that has been used to reduce heavy metal contaminant mobility and toxicity. Exposed shoreline tailings comprising 40.5 acres (16.4 ha) located on the southern perimeter of Pond 2 in the Warm Springs Operable Unit were to be wet closed, with Pond 2 discharge being required to meet Interim Water Quality Standards. Field studies were undertaken to evaluate the suitability of direct surficial lime additions to exposed tailings. Results indicated that lime slurry application rate of 8.96 Mg/ha (4.0 t/ac) would be optimal in reducing metal release into the overlying water column. Metal concentration in Pond 2 discharge during closure showed slightly higher dissolved Cu concentrations (0.055-0.105 mg/L) than predicted from column studies (0.050 mg/L). Limnological processes within Pond 2 related to the spring algal bloom and lake turnover was

believed responsible for the observed differences.

ACIDIC DRAINAGE CHARACTERISTICS AND RESIDUAL SAMPLE MINERALOGY OF UNSATURATED AND SATURATED COARSE PYRITIC TAILINGS
Paktunc, A.D.; Dave, N.K.
Sud99, V1, pg 221

Abstract: Column leaching experiments were conducted for evaluating the oxidation and leaching characteristics of coarse pyritic uranium tailings with and without limestone amendments under unsaturated conditions and tailings submerged under a shallow water cover. The unsaturated tailings without limestone amendment oxidized rapidly producing highly acidic drainage. The coarse limestone amended tailings also oxidized and produced highly acidic drainage. However, the onset of the acidic drainage occur with 90% of the available alkalinity still remaining in these samples. The tailings amended with fine limestone did not produce any acidic drainage during the entire 7.5 year study period. Although oxidation and acid generation processes were active, the fine limestone provided complete acid neutralization preventing acidic drainage during the study period. The submerged tailings did not produce any porewater acidic drainage for the first three years, but in the fourth year a weak acidic drainage appeared and continued to occur during the rest of the study period. In comparison to unsaturated tailings, the saturated conditions decreased cumulative porewater acidity, sulfate and iron loadings.

The mineralogy of the leached samples identified the principal components as quartz, K-feldspar, muscovite and pyrite. There is a substantial decrease with near depletion of pyrite in the upper most section of the leached tailings and a gradual increase in the pyrite concentration with depth towards the bottom of the column. Pyrite grains are strongly rimmed with variable alteration features. Pyrite occurs as mostly liberated particles displaying subangular to angular shapes with variable rimming and dissolution features. Fe-oxyhydroxides occur as secondary product layers around pyrite particles and along microfractures in pyrite as a replacement product under unsaturated leaching conditions. In contrast, only trace levels of Fe-oxyhydroxides developed under saturated or submerged conditions.

Unsaturated conditions with very fine grained limestone amendment and submerged conditions without any amendment proved to be effective in controlling or delaying the onset of acidic drainage and accompanying metal release from the tailings.

DECOMMISSIONING AT KRISTINEBERG MINE, SWEDEN
Lindvall, M.; Eriksson, N.; Ljungberg, J.
Sud99, V3, pg 855

Abstract: The Kristineberg mining area in northern Sweden is subject to a decommissioning plan more complex and extensive than an other decommissioning project ever carried out in Sweden. the mining area comprises a large tailings area and five mines, a large central industrial area which includes an old concentrator and three open pits. Parallel to the decommissioning project, the Kristineberg mine will be operated and further developed towards new, promising ore findings more than 1000 m below ground level.

This paper focuses on the decommissioning of the tailings area, which provided the greatest challenge. The tailings area consists of five individual ponds with varying characteristics.

The solutions selected were individually designed according to the specific conditions of each pond. both till covers and flooding are practiced. One innovative method that has been successfully applied is ground water saturation accomplished by means of surface water control and a simple till cover increasing the ground water level.

In order to finally incorporate the tailings area into the surrounding environment the Vormbacken Creek, which had previously been diverted around the tailings ponds will be rediverted into the lower ponds turning them into artificial lakes naturally interacting with the creek.

The MiMi research program, funded by the Foundation for Strategic Environmental Research (Mistra), have decided that Kristineberg will be the main test site for the program during the first phase, 1998-2000. The most important incentive for choosing Kristineberg is that it provides unique opportunities to study various types of waste products under different conditions, as well as the effects of a number remedial measures already implemented.

A3.3. Flooding Underground Mines

THE "LOKKEN PROJECT" - FLOODING A SULFIDE ORE MINE
Arnesen, R.T.; Iversen, E.R.
Van97, V3, pg 1093

Abstract: In October 1983 a part of the Lokken mine (The Wallenberg Mine), which had been sealed off from the rest of the mine, was abandoned, and the mine was gradually flooded by natural inflow. In 1986 NIVA started monitoring the water in the mine by taking samples in the Wallenberg shaft down to level 490 m. The samples indicated that the water quality in the mine changed during the flooding. Water samples from the mine were of two different types, nearly unpolluted surface water and mine water with some retention time in the mine.

From the flooding started until the first sampling, concentrations of some important pollutants in the mine water changed markedly. At level 490 the following changes were found: pH increased from 2.0 to nearly 4.0, copper decreased from 530 mg/L to 1 mg/L, and zinc increased from 1500 mg/L to 4000 mg/L. Sulfate was not analyzed in the mine water before the flooding. The concentrations found in the first samples from level 490 were so high (about 70,000 mg/L) that it was not probable that the concentrations had decreased significantly during this time. Iron in practically all samples was ferrous. In samples from the deeper part very high concentrations of carbon dioxide were detected. The following explanation of the changes in water chemistry is suggested:

- Ferric iron in contact with pyrite is spontaneously reduced to ferrous iron
- Alkaline rock neutralizes acid drainage
- Copper in mine water will be exchanged with iron and zinc in the ore.

Based on the results of the flooding, the mine acid seepage from the waste rock dumps in the area is today directed into the old part of the mine and water is pumped from the Wallenberg shaft to maintain a constant water level. This resulted in a substantial reduction in the pollution load from the Lokken mine site. The total load of copper from the Lokken area has been reduced by more than 95% since 1983. The load of zinc has also been reduced, probably about 90%.

EFFECTS OF ORE BODY INUNDATION-A CASE STUDY
Neukirchner, R.J.; Hinrichs, D.R.
Van97, V4, pg 1469

Abstract: Inundation of an ore body is a potentially effective way in which to reduce the impact of acid rock drainage. The reduction in available oxygen resulting from inundation of an ore body can result in a reduction in the acid generation potential and a consequent improvement in contained water quality. The Eagle Mine, located near Minturn, Colorado, was a major producer of zinc and lead concentrates until mining operations were discontinued in 1977. The ore body which sustained the mine is composed mainly of pyrite, sphalerite and galena. Flooding of the inactive workings, begun in 1983, has raised the water level by about 700 feet and has submerged about 80% of the mined ore body.

Water quality measurements over the period 1989-1996, after the rise in mine water level had stopped, document the improvements in water quality which have occurred. The pH of the mine water has increased from about 3.0 in 1989 to about 6.0 in 1996. Dissolved zinc concentrations have dropped from about 350 mg/L in 1989 to about 20 to 50 mg/L in 1996. These changes in mine water chemistry result in reduced chemical usage and reduced sludge production at the site water treatment plant. Flooding of the Eagle Mine has also reduced mine inflow by about one third.

ESTIMATING CONTAMINANT CONCENTRATIONS IN A RE-FLOODED UNDERGROUND MINE
Hockley, D.; Chapman, J.; Sevick, J.; Moe, D.
Tmw98, pg 517

Abstract: Investigations were undertaken to characterize the potential for various underground components of the proposed Crandon Mine to release contaminants to ground water that will re-flood the mine after operations cease. Methods used to characterize the sources included literature and data review, laboratory tests and simple calculations. The potential for backfilled tailings to release contaminants to the groundwater was shown to be limited by the rate at which oxygen can be transported into the backfilled stopes. In assessing the potential for the wall rock and crown pillar to release contaminants, key parameters were the proportion of wall that will be sulfidic, and the actual surface area of the walls. Conservative estimates of contaminant emissions from diesel equipment were used to show that underground emissions are not likely to contribute a significant amount of contaminants to the ground water. The investigations also included an analysis of ground water flow patterns in the re-flooded mine, which led to the conclusion that the ground water quality will initially be dominated by contributions from wall rock in the access workings, but subsequently will be dominated by the backfilled tailings.

A3.4. Lakes

GEOCHEMISTRY OF SUBMERGED TAILINGS IN BUTTLE LAKE AND THE EQUITY SILVER TAILINGS POND, BRITISH COLUMBIA, AND ANDERSON LAKE, MANITOBA: WHAT HAVE WE LEARNED?
Pedersen, T.F.; McNee, J.J.; Flather, D.; Sahami, A.; Mueller, B.; Pelletier, C.A.
Van97, V3, pg 989

Abstract: The post-depositional chemical behavior of submerged mine tailings has been evaluated using

high-resolution pore water sampling in a number of lakes and a tailings pond. The results outline three modes of behavior, which imply that sulfide-rich tailings either: a) do not release metals (e.g. Zn, Cu, Pb) to solution when stored permanently underwater, as seen in Anderson Lake; or b) exhibit minor remobilization of some metals (e.g. Zn) which can be related to diagenetic cycling of oxide phases, as seen in Buttle Lake; or c) release certain metals (e.g. As) apparently from soluble alteration products that form during milling and/or processing of the ore, as seen in the tailings pond and Equity Silver.

Recent data presented in this paper in support of these observations yield three main conclusions. First, pyrite and pyrrhotite rich tailings deposited in Anderson Lake, Manitoba, show no evidence of oxidation at a purposely-selected shallow turbulent site where the water column in summer is continuously well oxygenated. Indeed, multiple dissolved Zn, Cu and Pb profiles across the sediment water interface show that these dissolved metals are diffusing from the water column into the tailings, as has been previously observed elsewhere in the lake.

Second, there is no evidence that pyrite rich tailings are oxidizing on the floor of the south basin of Buttle Lake, despite the passage of more than a decade since discharge of tails ceased. The tailings are now being progressively covered with natural sediments that guarantee future storage of the deposits in a perpetually anoxic state. However, ongoing diagenetic metal cycling in Buttle Lake sediments is responsible for limited release of zinc to bottom waters. This is attributed to the adsorption of zinc from the water column onto manganese and iron oxide phases, and the subsequent diagenetic cycling of these phases during the early stages of burial. The source of the dissolved zinc in the lake is not the tailings, but acid rock drainage from the nearby mine site which is delivered to the south basin by surface runoff.

Third, the slightly alkaline, arsenic rich deposits (up to 1.8 wt% As) in the Equity tailings pond are releasing As to the pore waters, but are taking up antimony, which is diffusing in form the overlying water. Dissolved oxygen data show that the tailings are anoxic at a depth of a few cm, but the redox gradient does not appear to influence the As and Sb distributions. The data imply that the pore water arsenic enrichment is due to dissolution of some soluble phase, presumably an alteration product, and that the uptake of Sb is due to active precipitation of an unknown authigenic mineral or minerals, possibly and antimony sulfate phase. The uncertainty regarding the sources and sinks for the two elements reflects, in part, the lack of historical data on the compositions of discharges to the Equity pond during the lifetime of the mine. Overall, the various MEND studies that have been carried out, particularly those in lakes, strongly support the original subaqueous disposal hypothesis: the storage of sulfide rich tailings underwater, if properly conducted, can be an environmentally sound and permanent disposal option.

CONTRASTING TRACE METAL DYNAMICS IN CONTAMINATED LAGO JUNIN, PERU AND SUBMERGED TAILINGS DEPOSITS IN CANADIAN LAKES: THE IMPORTANCE OF PERMANENT SUBMERGENCE

Pedersen, T.F.; Martin, A.J.; McNee, J.J.

Sud99, V1, pg 165

Abstract: ARD derived from oxidized subaerial tailings or waste rock deposits has become a serious contaminant of surface and ground waters in almost all countries that practice mining. But this needn't be so. Recent research carried out on submerged sulfide-rich tailings deposited permanently under water shows that the rates of generation of acid and release of metals are

either negligible or are so low as to have no measurable impact on water quality. This conclusion is supported by detailed analyses of interstitial waters collected over several years in repeated sampling campaigns in Anderson Lake, Manitoba and Buttle Lake, British Columbia. Both lakes host permanently submerged tailings, and in both cases the tails are sequestering metals rather than releasing them to the overlying bottom waters.

In settings where sulfide-bearing materials are cyclically submerged, exposed to air and resubmerged, the results are dramatically different: metals are released following resubmergence. The environmental threat posed by such releases is illustrated by data collected in Lago Junin, Peru. This large shallow lake is badly contaminated as a result of inputs for several decades of tailings, ARD, and tailings pond effluents. The contamination is exacerbated by releases of Cu and Zn from contaminated shallow sediments in the lake that are alternately wetted and dried. In contrast, deposits in the deeper and permanently submerged main basin serve as a sink for all trace metals studied except zinc which is liberated at the sediment-water interface, probably from decaying organic matter that has settled through the contaminated water column.

A PROPOSED METHOD OF UNDERWATER CAPPING FOR TAILINGS DISPOSAL
Zou, D.H.S.; Huang, Y.
Sud99, V2, pg 671

Abstract: Proper disposal of mine tailings would prevent acid drainage, protect the environment and enable land reuse. In recent years, many research projects were initiated and various disposal methods, such as dry and underwater covers, are being developed. Although encouraging results have been reported, some fundamental issues remain to be resolved: the sustainability of the solutions, the potential leaching of contaminants due to ground water seepage, and the reuse of land. In this paper , a permanent tailings disposal method is proposed. The objective is to cover the submerged tailings underwater by an impermeable cap. The cap can be formed by grouting the top layer of tailings or by capping the tailings directly underwater in tailings ponds. It well serve as a barrier to isolate the tailings from air, prevent oxidation, stop transportation of contaminant and form a base for site reuse. Laboratory simulations were successfully conducted using a special binder which could absorb large quantities of water and could set fast in water. Simulations included underwater grouting and solidification. The formed cap developed a uniaxial compressive strength of 0.7 to 1.0 MPa in 7 days without aggregates and at water/binder ratios of 2 to 3. Adding 20% sands increased the strength by up to 192%. The failed samples showed up to 27% strength increase 20 months later. No cracking was observed during this period. These results indicated the possibility of permanently covering the tailings in situ by underwater capping directly in tailings ponds.

WETLAND PLANT ESTABLISHMENT AND GROWTH IN TAILINGS ENGINEERED WITH WATER COVERS
Beckett, P.J.; Tisch, B.; Wilkinson, F.
Sud99, V2, pg 691

Abstract: Several options currently exist for the decommissioning of acid generating tailings, including the containment of tailings under a permanent, engineered water cover by flooding or subaqueous disposal. Where sites allow, the flooding option has been successful in eliminating acid mine drainage. Since substrates are saturated in the case of flooded tailings, and wetlands require similar hydrological conditions, these sites provide the opportunity to enhance the site through the establishment of wetland and aquatic vegetation. As an organic

cover over flooded tailings should further impede oxidation of the tailings, this treatment would be suitable in conjunction with an already existing water cover.

Research was initiated on flooded pyritic uranium tailings near the city of Elliot Lake, Ontario. In 1993 vegetation 'islands' of several shoreline species were transplanted into 30-60 cm of water. By 1998 the diameters of the patches has increased by several hundred percent. In 1995 a large-scale transplant was undertaken to establish vegetation in deeper water. White water lily, pickerel weed, pondweed, watershield, hardstem bulrush and bladderwort were planted in 50 locations ranging in depth from 0.3-4.5 m. Survival rates in 1996 and subsequent years were recorded near 40% for fragrant water lily, 80% for pickerel weed and 60% for hardstem bulrush. Generally, the production of leaves and biomass was reduced on the tailings,. There was little change in elemental, nutrient and radionuclide concentrations in plants introduced into the waste management area compared to the source sites. In 1997 and 1998 wetland plants were transplanted into plots of paper mill sludge. Survival and growth rates have been higher than plants that were directly transferred to tailings. Nitrogen and phosphorus amounts were the major limiting factors to growth of Richardson's Pondweed.

A3.5. Open Pits

SUPPRESSION OF SULFIDE MINERAL OXIDATION IN MINE PIT WALLS PART 1: HYDROLOGIC MODELING
Warren, G.C.; Brown, A.; Meyer, W.A.; Williamson, M.A.
Tmw97, pg 425

Abstract: Due to increasing levels of TDS, SO_4, and Ca, and a corresponding decrease in alkalinity of an open pit lake, consideration has been given to diverting surface water into the open pit. The diversion of surface water is expected to suppress the potential formation of acid in the pit water through inundation of sulfide bearing materials on the exposed pit walls, and dilute current concentrations of dissolved solids. In order to evaluate future open pit lake levels and water chemistry resulting from diversion of surface water, a mass balance model has been developed. The results of the model under the diversion and non-diversion cases were compared to determine whether the introduction of surface water into the pit lake would be beneficial in reducing the potential formation of acid in the lake without compromising the quality of ground water outflow through the open pit walls.

SUPPRESSION OF SULFIDE MINERAL OXIDATION IN MINE PIT WALLS PART 2: GEOCHEMICAL MODELING
Meyer, W.A.; Williamson, M.A.; Warren, G.C.; Brown, A.
Tmw97, pg 433

Abstract: An open pit has been filling since gold mining ceased. In the pit, water quality samples show that TDS, SO_4, and Ca concentrations have risen at the same time that alkalinity has decreased. The pH of the pit water has remained constant at about 8.0 while metals generally have been below their respective detection limits. As part of planning to close the open pit, consideration has been given to diverting surface water into the open pit to suppress the formation of acid in the pit water by inundating exposed sulfide minerals.

Part 1 of this series discusses the hydrology and engineering involved with the conceptual

model of diverting surface water into an open pit mine, and Part 2 discusses the geochemical principles used to predict the future water quality and the subsequent results. The approach used to model the geochemical evolution of water quality was a two-staged process. A straight-forward mass flux calculation, combined with historic pit water quality data, accounted for measured and modeled solution flow into the pit. Once mixed, the geochemical equilibrium program MINTEQA2 was used to perform speciation and saturation calculations. The mass balance model included the precipitation of oversaturated solid phases determined using MINTEQA2. The model was calibrated using nine years of pit water quality data and successfully reproduced the concentration-time profiles for major constituents such as Ca, Mg, SO_4, alkalinity and TDS. Predictions about future pit water quality were made for scenarios with and without surface water diversion under three different runoff regimes.

Results of the simulation were evaluated to determine the benefit of surface water diversion to suppress sulfide mineral oxidation and the subsequent production of acidity and trace metals. MINTEQA2 results indicate that the open pit is in equilibrium with respect to calcite, and gypsum equilibrium was used as an upper boundary for Ca and SO_4 concentrations. Trace metal predictions for Al, As, Cd, Cr, Fe, Mn, and Zn were attempted, but concentrations appear to be lower than predicted because of adsorption and co-precipitation mechanisms present in the pit.

APPROACH USED TO MODEL PIT FILLING AND PIT LAKE CHEMISTRY ON MINE CLOSURE-VOISEY'S BAY, LABRADOR

Bursey, G.G.; Mahoney, J.J.; Gale, J.E.; Dignard, S.E.; Napier, W.; Reihm, D.; Downing, B.

Van97, V1, pg 257

Abstract: A Baseline Hydrogeological Survey (BHS) is underway at Voisey's Bay, Labrador. The overall goal of the BHS is to establish the baseline hydrogeological and hydrogeochemical conditions in the area of the proposed open pit, provide predictive numerical model simulations of ground water inflows into the open pit, and predictive geochemical simulations of the composition of water in the pit lake after mining ceases.

Baseline hydrogeological conditions were established through a series of detailed field investigations between October 1995 and October 1996. More than 300 existing exploration boreholes provided data on water levels, bedrock permeabilities, and general water chemistry. It was necessary to drill, sample and test another dozen boreholes/monitoring wells in both overburden and bedrock to properly characterize baseline conditions. Approximately 100 water samples were analyzed for general water chemistry and trace metal contents. Permeability testing was conducted in about 20 vertical and inclined boreholes that intersected 1,500 to 2,000 m of fractured bedrock.

As expected, preliminary MODFLOW modeling results show that excavation of the open pit will influence the local boundary conditions and will modify ground water flow. Higher inflows are predicted during the initial stages of pit development. Rainfall and snowmelt will dominate the peak pit inflows and will represent the largest volume of water that will have to be managed at the mine. After mine closure, the time to fill the open pit is dependent on the water management strategies that are adopted. A geochemical modeling approach, using the equilibrium speciation code PHREEQC, will be applied to predict the chemistry of the pit lake that may form after closure. A brief comparison is provided between the approach used in this study and MINEWALL 2.0, which was developed under the MEND program. This work is currently in progress and, consequently, this paper will discuss methodology and approach rather than results.

VERTICAL TRANSPORT IN BRENDA MINES PIT LAKES
Hamblin, P.F.; Stevens, C.L.; Lawrence, G.A.
Van97, V1, pg 367

Abstract: ARD generates fluid with elevated acid levels. Environmental concern requires that this fluid be controlled and only released at suitable pH levels. Subaqueous disposal is a technique that can, under suitable circumstances, delay or mitigate release into the surrounding environment of material such as that generated by ARD or containing high levels of dissolved compounds. The technique requires that the material in question be placed under a relatively inert cap of lighter fluid in a deep basin such as that left after mining. In many situations, because of low diffusion rates, the material will have effectively been disposed. However, there are a number of naturally occurring physical mechanisms that can quite efficiently bring this material to the surface and hence the surrounding environment. Here we describe a modeling application to the Brenda Pit Lake using an extended version of the lake and reservoir water quality model, DYRESM, incorporating algorithms for detailed ice cover, heat fluxes and also internal wave-driven boundary mixing. Sheltering and shading of the meteorological forcing is taken into account in the model. Both the field data and the model confirm the capping effects of the fresh water cap overlying the relatively salty water in the pit.

LIMNOLOGIC CONDITIONS IN THREE EXISTING NEVADA PIT LAKES: OBSERVATIONS AND MODELING USING CEQUAL-W2
Atkins, D.; Kempton, J.H.; Martin, T.; Maley, P.
Van97, V2, 697

Abstract: Limnologic processes that influence the evolution of mine pit lakes include the production of biomass and hydrodynamic mixing. Biological productivity may influence wildlife use, and when combined with lake hydrodynamics, affects the dissolved oxygen distribution and the corresponding chemical reactions in the lake.

Limnologic parameters (T and DO profiles, plankton speciation and abundance, and nutrient concentrations) were measured in three existing pit lakes in Nevada to develop a database to support predictions of limnologic conditions in future mine pit lakes. Two of the lakes were thermally stratified during summer sampling and completely vertically mixed during winter, whereas the third lake was completely mixed in summer and winter. The first lake formed when and open pit copper mine was flooded by rebounding ground water; it has a maximum depth of 110 m, and is seasonally stratified, well oxygenated, and oligotrophic. The second lake formed in an open pit gold mine, has a maximum depth of 17 m, and is a seasonally stratified, mesotrophic lake that develops an anoxic hypolimnion at the end of the summer stratified period. The third lake also formed in an open pit gold mine, at a maximum depth of 7 m, and is an isothermal, saline, well oxygenated, oligotrophic lake.

Data from the field study were used to develop limnological models of the lakes using the U.S. Army Corps of Engineers hydrodynamic and water quality model CE-QUAL-W2. The model sufficiently describes major limnologic processes, including seasonal variations in temperature and dissolved oxygen concentration, supporting the use of this model to simulate hydrodynamic conditions and biological productivity in mine pit lakes. Information from the field and modeling study is being used to simulate future limnologic conditions in lakes such as the Twin Creeks mine pit lake, which have not yet formed.

PREVENTION OF ACID ROCK DRAINAGE THROUGH THE APPLICATION OF IN-PIT DISPOSAL AND ELEVATED WATER TABLE CONCEPTS

Orava, D.A.; Tremblay, G.A.; Tibble, P.A.; Nicholson, R.V.

Van97, V3, pg 971

Abstract: The placement of mine wastes in mined out open pits, and the use of elevated water tables within tailings, are concepts that are increasingly being considered for the permanent disposal of sulfidic mine wastes that have the potential to produce ARD. These scientifically founded concepts can, where site specific conditions allow them to be applied, for the technical basis of closure plans. When these concepts can be applied, significant benefits may be achieved in terms of inhibiting acidic drainage, and meeting other closure options.

In-pit disposal has been applied to inhibit the production of acidic drainage from mine wastes. The performance of this concept relies principally on the water saturation of interstitial pore spaces in sulfide waste materials to establish an atmospheric oxygen diffusion barrier. In-pit disposal programs may also involve: i) the addition of alkaline materials such as calcium carbonate to neutralize acidity; ii) the use of low permeability perimeter zones or other means to minimize ground water flow through the wastes contained within pits; and iii) the use of a pit lake water cover.

An elevated water table within tailings offers a means of inhibiting the oxidation of sulfide tailings through the effective saturation of interstitial pore spaces. Sulfide minerals below the water table are not available for rapid oxidation and raising the water table effectively reduces the inventory of oxidizable sulfide in the tailings. The application of this concept may, however, not prevent acid production from near surface tailings. Variations involve taking measures to: i) modify the water balance of the tailings so as to increase net inflow of water to the tailings; ii) enhance the water retention ability of the tailings; and iii) provide barriers to ground water flow within the tailings.

OPEN PIT RECLAMATION AT THE KENNECOTT RIDGEWAY GOLD MINE

Dorey, R.; Willow, M.; Duckett, R.

Tmw99, pg 701

Abstract: The Kennecott Ridgeway Gold Mine, located outside Ridgeway, South Carolina, is scheduled to complete mining and ore processing in late 1999. The project completed mining in its South Pit in 1996. As part of the overall reclamation planning for the project, methods to manage sulfide bearing waste rock and exposed sulfides in the pit walls were developed to allow reclamation of the pits as fresh water lakes. Through detailed waste classification and amendment addition to both waste rock and pit water, the pit is being backfilled using amendment addition to both waste rock and pit water, the pit is being backfilled using subaqueous disposal to alleviate sulfide oxidation while maintaining satisfactory quality pit water. Development of methods to measure stored acidity in the waste rock and monitoring of pit water quality were required. Design of a liquid base amendment addition system and the detailed sequencing of rock placement and water management were intrinsic to the success of this approach to pit reclamation. Since 1996, the monitoring programs have shown that a high quality water is being maintained in the South Pit.

APPENDIX 4

Annotated Bibliography of References
Enhanced Surface Reclamation of Reactive Mine Wastes
Bactericides

A4.1. Overview of Bactericide Studies
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A4.1. Overview of Bactericide Studies

Since mineral potential in Minnesota is largely associated with metallic minerals, this presentation focuses on the application of bacterial inhibitors to sulfidic mine wastes rather than coal mine wastes. Very few studies have been conducted on metal mine wastes using bacterial inhibitors. The majority of these studies evaluated the ability of surfactants such as sodium lauryl sulfate (SLS) to inhibit bacterial growth, thereby reducing drainage acidity and dissolved metal concentrations (Patterson, 1987; Sobek, 1987; Watzlaf, 1988; Parisi et al., 1994). Two studies evaluated the effectiveness of heterocyclic mercaptans (Stichbury et al., 1995; Lortie et al., 1999). The purpose of this section is to review the results of these studies in terms of parameters used to indicate bacteria inhibition (i.e. pH, acidity, chemical release, and bacteria counts; Tables 2 and 3).

A4.1.1. Surfactants

The type of surfactants used and application methods varied widely in the studies reviewed here. In three instances, the surfactant used was not identified (Patterson, 1987; Sobek, 1987). SLS was the most commonly tested surfactant, however, Watzlaf (1988) also tested potassium benzoate and potassium sorbate.

Surfactant concentrations were not always reported, although laboratory test claimed to be used to determine appropriate dosages. Based on the two studies that did report surfactant dosages, the field test (Parisi et al., 1994) used a dosage that exceeded the dosage used in unrelated laboratory tests (Watzlaf, 1988) by one to three orders of magnitude.

Test duration varied from a set of eight week laboratory experiments (Sobek, 1987) to a fifteen month field trial (Parisi et al., 1994). As a result of these differences, it was difficult to make valid comparisons between studies.

In general, surfactant effectiveness was reported in terms of the percent reduction in acidity. Application of surfactants during laboratory studies reduced acidity by 50% - 70% when adequate surfactant dosages were used (Sobek, 1987; Watzlaf, 1988). Of the two field studies reviewed, only one was considered successful with acidity reduced from 2500 mg/L to 200 mg/L, or approximately 92% (Parisi et al., 1994). Direct measurements of pH were not reported in any of the laboratory studies and rarely reported for field test sites. Parisi et al. (1994) reported that drainage from waste rock at a silver mine had an average pH of 5.6 during the fifteen month study. These reported results suggest that while drainage acidity was greatly reduced, drainage pH was probably not maintained above the environmental standard of 6.0.

In one study, surfactant effectiveness was determined by chemical release in the drainage. Patterson (1987) reported on a laboratory study in which a 50% reduction (500 to 250 mg/L) in copper release to solution was used as an indicator of SLS effectiveness (Patterson, 1987).

Similarly, a field test at a silver mine reported decreases in sulfate concentrations from 1000 mg/L to 300 mg/L (Patterson, 1987).

A third method used to determine surfactant effectiveness is to estimate bacteria population size. Watzlaf (1988) used a most probable numbers method to determine that SLS and potassium benzoate inhibited bacterial growth in batch leach tests for 182 and 231 days, respectively.

A4.1.2. Heterocyclic Mercaptans

Two papers dealt with the application of heterocyclic mercaptans to sulfidic wastes (Stichbury et al., 1995; Lortie et al., 1999). Both papers report on the same basic study, using 2,5-dimercapto-1,3,4-thiadiazole (DMT) and 5-amino-1,3,4-thiadiazole-2-thiol (ATT) as bacterial inhibitors. Stichbury et al. (1995) focused on laboratory experiments conducted over a six week period. In the laboratory experiments, 20 g of fresh tailings and 0.5 g oxidized tailings were treated with 85 ml of inhibitor (at 100, 200, or 500 mg/L) and 5 ml of culture medium containing *T. thioparus*.

Field test plots consisted of plastic barrels (d = 53 cm, h = 82 cm) filled with fresh tailings and backfilled into an old tailings area (Lortie et al., 1999). Test plots were treated with 500 mg inhibitor per kilogram of tailings and monitored for approximately one year.

In both cases, pH values were reported as indicators of inhibitor effectiveness rather than acidity. In laboratory experiments, only one dosage of DMT (500 mg/L) resulted in a final pH above 6.0 (Stichbury et al., 1995). In all other cases, pH decreased below 5.0. After one year, cores were taken from the field test plots and cut into two sections, representing 0-25 cm and 25-50 cm depths (Lortie et al., 1999). Pore water pH in these sections decreased to 3.0 and 3.2, respectively, in the treated test plots compared to 3.5 and 4.2, respectively, in the control test plots.

The results of the laboratory experiments in terms of sulfate concentration were similar to the pH results in that sulfate production was inhibited only in the 500 mg/L DMT incubation. However, sulfate production in the field test plots was reduced from approximately 30,000 mg/L in the controls to 14,000 - 18,000 mg/L in the treated barrels. Thus, sufficient quantities of DMT appear to reduce sulfate production in these tailings by approximately 50% compared to untreated tailings.

Tailings pore waters from the field test plots were also analyzed for Fe, Al, Ca, Co, Cu, Mg, Mn, Na, Ni, and Zn (Lortie et al., 1999). Concentrations of five of these elements (Al, Co, Mg, Mn, and Na) were actually higher in the treated samples than in the controls. No significant differences were seen in concentrations of Ca, Cu, Ni, or Zn. Only iron concentrations were reduced below the levels found in the control samples (i.e. approximately 14,500 mg/L to 4000 mg/L).

The number of *T. thioparus* bacteria associated with each core from the field test plots were also estimated using a most probable numbers technique (Lortie et al., 1999). After one year, bacteria counts in the control samples had reached 10^5 to 10^6, whereas bacteria counts in the treated samples did not exceed 380.

A4.2. Bactericide Literature

Lortie, L.; Gould, W.D.; Stichbury, M.; Blowes, D.W.; Thurel, A. (1999) Inhibitors for the prevention of acid mine drainage. Sud99, V3, pg. 1191.

Abstract: Two chemicals that belong to a class of compounds that specifically block the oxidation of various sulfur compounds by thiobacilli were tested for their ability to inhibit AMD production in tailings and their effects on bacterial populations in a field study. The chemical interaction of these compounds with various minerals was also examined in a laboratory study. These compounds are 2,5, dimercapto-1,3,4-thiadiazole and 5-amino-1,3,4-thiadiazole-2-thiol, which are relatively non-toxic and odorless heterocyclic mercaptans. Shake flask studies have shown that these compounds inhibit the oxidation of thiosulfate by pure cultures of *Thiobacillus thioparus* and the oxidation of mine tailings in columns. These inhibitors block the oxidation of sulfur by neutrophilic thiobacilli such as T. *thioparus*, which has been postulated to be one of the initial successional events in the formation of acid drainage. Pyrite and other iron sulfides catalyze the oxidation of the inhibitor compounds to the corresponding disulfide or polysulfide which are the biologically active forms of these compounds. In a field study these compounds completely inhibited the growth of all groups of thiobacilli for eight months and the growth of *Thiobacillus ferrooxidans* for one year. The porewater chemistry of the field plots was also consistent with these compounds inhibiting iron sulfide oxidation. The soluble iron concentrations were three to four times higher and the sulfate concentrations were two times higher in the control plots than in the inhibitor plots respectively. these compounds have the potential for the in situ inhibition of acid rock and acid mine drainage. The most likely niche for these chemicals would be to prevent acid generation in waste rock while it is temporarily stored in exposed locations prior to disposal in pits.

Delaney, T.; Hockley, D.; Sollner, D. (1997) Applications of methods for delaying the onset of acidic drainage. Van97, V2, pg 795.

Summary: The oxidation rate of ferrous iron is greatly enhanced by bacteria which catalyze the reaction. These bacteria thrive in the low pH environment that results from iron oxidation because of a protective greasy coating. Sulfide oxidation can be greatly slowed by destroying the bacteria through the application of surfactants which alter this protective coating. These surfactants are specific to *T. ferrooxidans*. Bactericides slow oxidation by removing the catalyst.

Bactericides are normally obtained in the form of a powder. The powder can be mixed with water to form a slurry which is then sprayed on the pile. Alternatively, the powder can be mixed with the waste during pile construction. However, bactericide powders are easily flushed from the rock or breakdown over time, necessitating reapplication every three to six months. Currently, bactericides are also available in time-release pellets that continue to release surfactants for longer than seven years. Case studies presented.

Stichbury, M.; Bechard, G.; Lortie, L.; Gould, W.D. (1995) Use of inhibitors to prevent acid mine drainage. Sud95, V2, 613.

Abstract: Chemicals that specifically block the oxidation of various sulfur compounds by neutrophilic thiobacilli were tested in shake flask studies. Two relatively non-toxic thiol-blocking agents, 2,5-dimercapto-1,3,4-thiadiazole and 5-amino-1,3,4-thiadiazole-2-thiol, were evaluated. Both compounds inhibited the oxidation of thiosulfate by pure cultures of *Thiobacillus thioparus* and the oxidation of fresh tailings by mixed cultures. In pure culture, complete inhibition of thiosulfate oxidation was observed when 1000 mg/L of either compound was added and partial inhibition at inhibitor concentrations of 100 mg/L. In tailings culture, 5-amino-1,3,4-thiadiazole-2-thiol was less effective than either 2,5-dimercapto-1,3,4-thiadiazole or an equimolar mixture of the two inhibitors. These compounds have potential for the in situ inhibition of AMD.

Ziemkiewicz, P.F. (1995) Acid mine drainage control technologies. Ch 5. Acid Mine Drainage Control and Treatment. West Virginia University and the National Mine Land Reclamation Center, Morgantown, WV.

Summary: Bactericides are used to control the bacteria which catalyze the conversion of ferrous to ferric iron which aids in the dissolution of pyrite. They are used in situations where immediate control of AMD formation is important. Bactericides are relatively low volume, often liquid amendments and are therefore easy to handle and apply. They can be applied to coal or refuse conveyor belts or sprayed by tricks on pads in the backfill. Bactericides have been used at both coal and metal mines. Bactericides are most effective when applied to fresh, unoxidized sulfides. Bactericide application was initiated in 1988 on a 4.5 ha refuse site in Pennsylvania. It was applied via a hydroseeder at an application rate of 225 kg/ha. Successive applications have been made every two to three months depending on the rate of reject depositional Average daily flow from the site was 300,000 L and there was a 79% reduction in acidity from 12,000 ppm to 2,500 ppm while iron was reduced by 82% from 4,000 to 710 ppm. Cost savings at the AMD treatment plant were $300,000 per year.

Bactericides, by themselves, are not seen as a permanent solution to AMD. Eventually the compounds either leach out of the rock mass or are decomposed. At that point either a new application is needed or a new treatment method would be implemented. Bactericides have promise in combination with other control methods. They would, for example, be useful in preventing acid conditions in pyrite rock piles which may remain open for several years until a dry barrier is placed.

Parisi, D.; Horneman, J; Rastogi, V. (1994) Use of bactericides to control acid mine drainage from surface operations. Pitt94, V2, 319.

Abstract: Anionic surfactants such as sodium dodecylbenzene sulfonate, sodium laurel sulfate and others are effective in controlling acid production from sulfidic materials such as overburden, coal, coal refuse, ores, waste rock, and tailings. Their use in practical mining and reclamation applications, however, is only being recently documented since longer term field data are only now becoming available. This paper describes three applications of bacterial inhibitors. The first is at a surface coal mine where special handling and bacterial inhibition have prevented acid drainage from highly pyritic (more than 0.5% pyrite, NP < 30 st/1000 st of $CaCO_3$ equivalent, and net deficiency of 15 st/1000 st of $CaCO_3$ equivalent) dark shale overburden for over 2 years. The second application is at an active refuse disposal area where alkaline addition at more than three times that indicated by acid-base accounting failed to control acid

production in refuse with 13% pyritic sulfur and neutralization deficiency of 444 st/1000 st $CaCO_3$ equivalent. Bacterial inhibitors were successful in reducing acidity and metals in site underdrain effluent by 88% to 90%. The third application was at a silver mine where waste rock containing up to 0.37% pyrite was treated with surfactant bactericides to reduce leachate acidity by 93% and sulfates by 70%.

772 Rastogi, V.; Sobek, A.A. (1986) The economics of using bactericides in active mining and reclamation to control acid mine drainage. National Symposium on Mining, Hydrology, Sedimentology, and Reclamation. University of Kentucky, Lexington, KY.

Abstract only: Methods for calculating the economic viability of using bactericides to control acid mine drainage are shown for active operations and reclamation. Only typical costs are used for these analyses. Three major segments of the mining industry which can benefit from the use of bactericides are: (1) Active Operations - an active surface mine or active refuse disposal site; (2) Final reclamation of a Mining Operation - a surface mine site or a completed refuse disposal area; and (3) Abandoned Mine Lands Reclamation. The economics of each segment varies as each has different end goals because of differing motivation.

An active operation's goals are to prevent site materials from becoming acidic, to prevent future acid mine drainage problems, and to minimize the costs of water impoundment and treatment. Goals for a final reclamation operation are to prevent drainage of acid water from the site, to avoid water treatment in perpetuity, to obtain acceptable revegetation, and to obtain bond release and future mining permits. In the case of abandoned mine land reclamation, the objective is to obtain aesthetically acceptable revegetation and resolve downstream sedimentation problems while preventing future water pollution.

In active mining, the cost of water treatment can be dramatically reduced or eliminated. In final reclamation of surface mining operations, the cost of topsoil can be reduced and the length of water treatment time can be considerably reduced or eliminated, while the incalculable costs of not obtaining bond release or future mining permits can be minimized. In AML reclamation, the cost of topsoil, lime, creating borrow areas, and future site maintenance can be minimized while ongoing water pollution problems can also be confidently resolved.

1003 Watzlaf, G.R. (1988) Chemical inhibition of iron-oxidizing bacteria in waste rock and sulfide tailings and effect on water quality. Mine Drainage and Surface Mine Reclamation Conference., Pittsburgh, PH.

Abstract: The effectiveness of sodium lauryl sulfate (SLS), potassium benzoate, and potassium sorbate in controlling the population of iron-oxidizing bacteria, thereby reducing acid production, was tested on sulfide tailings and waste rock. The waste rock was unweathered and contained 4.07% total sulfur, all in the pyritic form. Two different samples of sulfide tailings were used, and extensively weathered material (5.98 % total sulfur, 017 % pyritic sulfur, and 5.81 % sulfate sulfur) and a slightly weathered material (20.57 % total sulfur, 19.73 % pyritic sulfur, and 0.84 % sulfate sulfur). Two sample sizes were used in the experiment, 7 kg and 100 kg. The 100 kg samples of each material were treated once with a 600 mg/kg dose of SLS or potassium benzoate. The 7 kg samples were treated with a high (600 mg/kg) or a low (60 mg/kg) dose of SLS, potassium benzoate, or potassium sorbate. The treated samples and untreated control samples were subsequently leached once per week with filtered demineralized water (an amount equivalent to 2.5 cm of precipitation). For the 100 kg samples of waste rock, a single treatment of SLS and potassium benzoate completely

inhibited iron-oxidizing bacteria repopulation for 182 and 231 days, respectively. Acidity in the leachate from the 100 kg samples treated with SLS and benzoate remained below the untreated control for 287 and 343 days, respectively. Similar results were obtained from the 7 kg samples of waste rock. In the extensively weathered sulfide tailings, none of the treatments inhibited the iron oxidizing bacteria or reduced acidity levels in the leachate. In the slightly weathered sulfide tailings, all treatments reduced the bacterial populations, but did not significantly reduce acid production. However, in additional tests of the slightly weathered tailings, the removal of the weathered products prior to treatment with SLS or benzoate resulted in lower populations of iron oxidizing bacteria and reduced acidity levels.

1254 Kleinmann, R.L.P.; Erickson, P.M. (1988) Control of acid drainage from coal refuse using anionic surfactants. US BOM Report of Investigations 8847. 16p.

Abstract: To control the formation of acid drainage at its source, the Bureau of Mines has investigated the role of iron oxidizing bacteria in the oxidation of pyrite. In laboratory tests, it was determined that *Thiobacillus ferrooxidans* could be controlled in coal refuse using anionic surfactants, with an associated decrease in acid production of about 75%. Based on these results, large-scale tests were conducted at an 8 acre active coal refuse area in northern West Virginia and an 11 acre inactive refuse pile in southern West Virginia. Acid production was decreased 60 to 95% for 4 to 5 months after application of 55 gal/acre of 30% sodium lauryl sulfate solution. To date, effluent surfactant concentrations have been extremely low.

Either a hydroseeder or a road-watering truck can be used to apply the surfactant. Since the surfactant solution must reach the pyritic material to be effective, sites that have been reclaimed are generally not amenable to these procedures. A simple laboratory test is described that provides an estimate of adsorption potential; this can be used to calculate a safe application rate.

1255 Rastogi, V.; Sobek, A.A.; Benedetti, D.A. (1990) Prevention of water pollution problems in mining: The bactericide technology. Society for Mining, Metallurgy, and Exploration, Inc.

Abstract: Waste rock, sulfidic ore, coal and coal waste contain the bacteria *Thiobacillus ferrooxidans* that act as catalysts in acid formation. This acid solubilizes metals present in the site material and pollutes adjacent streams and lands.

Traditional treatment of runoff using neutralizing agents treats only the symptoms. It can also be excessively expensive, requiring large up-front capital expenditures for collection ponds and equipment, and heavy operating costs for chemicals, sludge removal and disposal, electric power, and personnel. Bactericide sprays on active operation sites attack the source of the problem by preventing acid formation and metal solubilization. In existing water treatment systems, bactericides can dramatically reduce operating costs. When incorporated into the mine design, bactericides can help reduce capital costs as well.

At the close of the mining operation, use of bactericides in the controlled release pellet form contributes to successful reclamation by providing assurance against vegetation burnout and post-reclamation water quality problems which can otherwise necessitate perpetual water treatment. Bactericides inhibit *Thiobacillus ferrooxidans* and aid in the establishment of beneficial heterotrophic bacteria necessary to support vegetation. These conditions persist after the bactericide is depleted from the controlled release pellets.

Use of bactericides begins with laboratory testing of the site material to determine bacterial activity, acid generation potential, and bactericide dosage required for remedial action. These site pre-qualification data from gold, silver, and coal mining predict site-specific effectiveness in field use as substantiated by actual results from active operations. Five years of water quality, microbiological and vegetation data from reclamation sites support the controlled-release benefits. Economic analyses illustrate the cost savings potential from several commercial applications at active operations and in reclamation.

1256 Benedetti, B.A. Rastogi, V.; Sobek, A.A. (1990) Minimizing water treatment costs at active operations. National Symposium on Mining, Knoxville, TN.

Abstract: Coal preparation plants, ore processing plants, coal tipples, refuse disposal areas, waste rock disposal areas, and slurry and tailings impoundments, have two things in common in areas where sulfides are present. They produce acid mine drainage and require extensive non-productive water treatment expenditures. Bactericides are now being used to mitigate acid production and drastically reduce overall water treatment and management costs. Data from commercial sites are used to compare the economics of different water treatment scenarios with and without bactericides.

1257 Sobek, A.A.; Benedetti, D.A.; Rastogi, V. (1990) Successful reclamation using controlled release bactericides: Two case studies. American Society for Surface Mining and Reclamation Conference. Charleston, WV.

Abstract: Controlled release bactericides affect reclamation success and provide assurance against post-reclamation water quality problems. They inhibit *Thiobacillus ferrooxidans* and aid in the establishment of beneficial heterotrophic bacteria necessary to support revegetation of the site. These conditions persist after the bactericide is depleted from the controlled release systems. Two coal refuse disposal areas, one in Ohio and one in West Virginia, were reclaimed using two different generations of controlled release bactericides. Case Study #1, located in Ohio, was reclaimed using first generation products with a release life of two years. Yet, six years after application, the treated area continues to have a dense vegetative cover while the untreated control area has only sparse vegetation. Water quality data from the treated area continues to show a significant improvement versus that from the control area. Case Study #2, located in West Virginia, was reclaimed using third generation products with a controlled release life in excess of seven years. In its third year, the vegetation is lush and healthy except for the control area where vegetation is becoming sparse due to acid toxicity. The water quality data from the treated area corroborates these improvements and justifies the use of bactericides in reclamation.

1526 Sobek, A.A. (1987) The use of surfactants to prevent AMD in coal refuse and base metal tailings. Proc. Acid Mine Drainage Seminar/Workshop, Halifax, Nova Scotia. March 23-26, 1987. pg 357.

Abstract: Thiobacilli bacteria, by direct or indirect mechanisms, oxidize metal sulfides and produce acid and soluble metals at a much faster rate than chemical oxidation. Elimination of these bacteria would inhibit acid formation. Several inorganic and organic compounds can inhibit thiobacilli growth; however, organic compounds are most effective. Anionic surfactants are some of the most effective organic compounds that are commercially available. Anionic surfactants become bactericides at low pH values. The short duration of these chemicals in the environment makes it necessary that a system such as the ProMac System, comprising a

quick-acting liquid spray with a long-term controlled release pellet, be used for permanent reclamation.

1539 Patterson, R.J. (1987) Environmental and reclamation measures at Equity Silver Mines Ltd. Proc. Acid Mine Drainage Seminar/Workshop, Halifax, Nova Scotia. March 23-26, 1987. pg 457.

Summary: The anionic surfactant, sodium laurel sulfate, has been tested to evaluate bacterial suppression methods within waste fills. Although the initial lab test work looked encouraging, results of in-field testing proved to be less than favorable. To be effective, a sufficient dosage of the soap product must be available to completely infiltrate the spoil through the oxidation zone. Reapplication is required. If acidic conditions pre-existed, then reapplication must be more frequent.

3496 Fox, L.A.; Rastogi, V. (1983) Developments in controlled release technology and its application in acid mine drainage. Symposium on Mining, Hydrology, Sedimentology, and Reclamation. University of Kentucy, Lexington, KY.

Abstract: It has been previously demonstrated that anionic detergents inhibit the bacteria *T. ferrooxidans* which otherwise catalyze the formation of acid drainage from pyritic material. Liquid sprays of these detergents are effective for short periods of time and are useful in satisfying overburden adsorption capacity and in initial rapid inhibition of bacteria. For a permanent solution, controlled release systems are needed to provide the required concentration of detergent over prolonged periods of time sufficient to permit healthy growth of vegetation on the reclaimed overburden. A good ground cover, when sustained over a period of years, will eventually deprive the spoil of oxygen and water needed to generate acidity. Different materials and configurations for obtaining desired rates of release of anionic detergents are described. Laboratory tests have been developed to analyze the release rates of the controlled release materials. These tests are used to determine application rates. Field trials have been conceived to verify application theories and to demonstrate long term effectiveness of these materials together with their biodegradability to insure that one environmental problem is not replaced by another. Laboratory and field tests are described and discussed.

3514 Kleinmann, R.L.P. (1980) Bactericidal control of acid problems in surface mines and coal refuse. Symp. Surf. Mining Hydrology, Sedimentology, and Reclamation, University of Kentucky, Dec 1-5, pg 333-337.

Abstract: A bacterium, *Thiobacillus ferrooxidans*, accelerates acidification of pyritic material and significantly increases the eventual level of acid production by catalyzing pyrite oxidation in the zone of aeration. Bactericides can be effective in reducing acid formation if added to infiltrating precipitation. However, the bactericidal treatment must be repeated frequently to prevent repopulation. To accomplish this at low cost, we have developed a controlled release technique involving diffusion and dissolution of anionic detergents from pellets of an elastomeric matrix. Release is expected to continue for approximately five years after application of the pellets.

The technique has been tested in the laboratory, on small coal refuse piles in central Pennsylvania and on hydrologically isolated sections of an abandoned surface mine in northern West Virginia. Detergent concentrations of approximately 25 ppm in the pyritic

material delayed or prevented acidification of coal refuse and reduced acidity of drainage from acid-producing material by 50 - 95%.

The US BOM is presently initiating larger-scale field tests of the technique to evaluate such potential problems as adsorption of the detergent to the clay particles and detergent contamination downstream. A two acre, revegetated surface mine in central West Virginia, which has associated with it an aid spring will be treated, as will one section of a 10 acre coal refuse pile in Pennsylvania and an abandoned surface mine in West Virginia.

3515 Rastogi, V. (1995) ProMac: bacterial inhibition. Mining Environmental Management, June, pg 27-29.

Summary: ProMac (Professional Mine Acid Control), patented by Ohio-based MVTechnologies, is designed to prevent bacterial catalysis of pyrite oxidation. There are two types of products: a powder which starts to inhibit bacteria immediately, and control release pellets which extend the life of the bactericide to more than six years.

In the reclamation of a coal waste disposal area, the ProMac bactericide treatment consisted of the powder and three forms of controlled release pellets, applied at the rate of 1350 kg/ha at a cost of $7,000/ha. The plots were covered with 45 cm of limed topsoil, fertilized, seeded and mulched using standard reclamation practices. The ProMac treatment performed far better than limestone and at lower cost.

APPENDIX 5

Annotated Bibliography of References
Alkaline Amendments

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A5.1. Overview of Alkaline Amendment Studies

Numerous studies have been conducted on the application of alkaline materials to neutralize acid released from reactive mine wastes. The purpose of this section is not to provide an extensive literature review of alkaline addition case studies. The following provides a brief overview of recent alkaline addition methodology and applications, including results from a few laboratory and field studies (Tables 4 and 5, respectively).

A5.1.1. Waste Rock

Laboratory studies

Stewart et al. (1994) reported on column studies using mixtures of fly ash, limestone, or rock phosphate with acid-producing coal refuse. The loadings of mitigative solid were varied and the tests were conducted for periods of two to three years. Coal refuse (2.3% S) was mixed with Westvaco ash mix (20% ash with an NP of 5 kg/t $CaCO_3$) in ratios of 4:1 and 2:1. Both ratios produced neutral drainage (pH 8) for three years, as compared to a control pH of 1.9. In a second phase, column experiments were conducted on various mixtures of coal refuse (4% S) with the Westvaco ash (5, 10, 20, and 33% loadings) and Clinch River fly ash (20 and 33% loadings). With the Westvaco ash, only the highest loading remained neutral after two years. The Clinch River ash (which was more alkaline than the Westvaco ash) maintained neutral drainage for two years, as did a 13% limestone mixture.

Limestone requirements to prevent acid generation and metal release from gold deposit mine wastes were evaluated in a five-year laboratory column study (Day, 1994). Each column tested a different blend of waste rock and limestone with NPRs ranging from 0 to approximately 1:1. The results indicated that a ratio of at least 1:1 is required to delay the onset of drainage acidification. The 1:1.11 limestone blend successfully prevented drainage acidification throughout the study, however, did not prevent zinc release. However, increasing sulfate concentrations, slightly decreasing pH, and acidic residues in the upper portions of the column suggested that the drainage will acidify in the future. Day (1994) concluded that the actual limestone requirement to delay acidification indefinitely would be at least 2:1.

Field studies

Waste materials have been blended with acid-producing mine wastes. Evans and Rose (1995) added lime kiln flue dust (an alkaline waste product) to 360 tons pyritic shale (1.9% S) in amounts providing neutralization potential 0 to 1.71 times the acid production potential. All conditions produced acidic drainage throughout the 10-month field test, although drainage pH increased from 1.9 to 2.6 as the flue dust loading increased. Incomplete mixing of the flue dust and shale, as well as preferential flow, were cited as limitations to the effectiveness of the treatment.

With metal mine waste rock, the blending and layering of limestone is reported to be of minimal mitigative success, due to problems such as inadequate homogeneity of mixtures and preferential flow through acid-generating layers (Mehling et al. 1997). The large particle size of the waste rock, the dimensions of which can reach several feet, most likely contributes to these problems. The reactivity of limestone is also limited when particle size is large.

Whereas ratios of NP:AP have been used to determine the amount of alkaline material required for maintaining neutral drainage from waste rock piles, analysis by Kempton et al. (1997) and Morin and Hutt (2000) indicate that preferential flow has a dominant influence on the effectiveness of waste rock blending. The latter publication indicated that waste rock drainage acidity is dependent on the flow path length within acid neutralizing rock separating zones of acid generating rock. The authors' analysis indicated that waste rock with a bulk NP:AP ratio of 300:1 could release acidic drainage if appropriate neutralizing rock flow path length was not attained.

A5.1.2. Tailings and Fine-Grained Waste Rock

With finer mine wastes (e.g. tailings or fine mine waste) and alkaline solids a homogeneous mixture can be more readily attained and, due to more uniform particle sizing, flow tends to be more uniform than in the wide range of particle sizes in waste rock piles. Blending of alkaline solids with tailings is further attractive due to 1) greater practicality in determining tailings composition within standard operating procedures; 2) their potential for a higher degree of compositional homogeneity over extended periods; and 3) the potential to achieve more intimate blends by moderate modification of standard tailings handling procedures. Furthermore, it may be necessary to treat only those tailings above the water table, since the rate of sulfide mineral oxidation below this level will be limited by oxygen diffusion through water.

For tailings, the operational phase is less problematic since drainage acidification tends to be limited by 1) the subaqueous environment in which the majority of tailings are disposed and 2) the typical addition of alkaline processing reagents to tailings impoundments. Furthermore, any problematic drainage that is generated can be collected and returned to the impoundment. However, after operations cease and before final closure measures are implemented, mitigation measures may be required, particularly in areas in which sulfidic tailings are not submerged. The addition of alkaline solids to tailings as the tailings are generated may be an effective, low-cost method of neutralizing acid produced during this period. It is also possible that such addition would accelerate the formation of precipitate coatings on the iron sulfide minerals responsible for acid production and, thereby, render these minerals much less reactive.

Laboratory studies

Some success has been attained in mixing limestone with finer acid-producing materials in the laboratory. Lapakko et al. (1997) reported that -10-mesh limestone homogeneously mixed with finely-crushed acid producing rock neutralized acid produced by iron sulfide oxidation. Furthermore, sulfide oxidation rates decreased to the extent that host rock mineral dissolution neutralized acid produced by iron sulfide oxidation after the limestone was depleted.

Lapakko et al. (2000) conducted laboratory tests under conditions similar to those used with the limestone blends, examining the effects of mixing rotary kiln fines (RK fines) with finely-crushed acid producing rock. Five loadings of RK fines were mixed with finely-crushed acid producing rock to produce neutralization potential (NP) added: acid potential (AP) quotients of 0, 0.11, 0.22, 0.66, and 1.1. The mixtures were subjected to wet-dry cycling for 585 weeks. The RK fines elevated pH and inhibited sulfate release for time periods which increased with the mass of RK fines present. The pH of drainage from the 1.1 quotient typically remained above 8.0 throughout the period of record.

Field studies

A lime amendment was incorporated at a historical abandoned tailings deposit (Davis et al. 1999). Site examination four to five years after the amendment revealed that the pH in pore waters of amended tailings was higher than values associated with unamended tailings. The authors also noted that trace metals were removed from pore waters in the amended tailings by sorption to ferrihydrite and/or coprecipitation. The authors concluded that lime amendment "represents a viable long-term alternative to mitigate a historical problem." Whereas this conclusion is generally consistent with the results presented, it may be premature based on the fairly short-term success. In addition, the paste pH of one tailings sample at an amended site was 4.7, despite a net carbonate value of 13 percent.

A5.2. Alkaline Amendment Literature

Compilation of this literature is not yet complete.

APPENDIX 6

Annotated Bibliography of References
Treatment Systems for Problematic Drainage

A6.1. Passive Treatment Systems
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A6.1. Passive Treatment Systems

Table A6.1.1. Bibliography of problematic drainage passive treatment studies conducted by the MN DNR.

Strategy	Study Scale	Reference
Wetlands	Natural Wetlands	Eger, P., Lapakko, K., Otterson, P. 1980. Trace metal uptake by peat: Interaction of a white cedar bog and mining stockpile leachate. In Proc. of the 6th International Peat Congress. Duluth, MN. Aug. 17-23, 1980. p. 542-547. Eger, P., Lapakko, K. 1988. Nickel and copper removal from mine drainage by a natural wetland. P. 301-309. In Proc. 1988 Mine Drainage and Surface Mine Reclamation Conference, April 19-21, 1988, Pittsburgh, PA. V. 1. Mine Water and Mine Waste. U.S.D.I. Bureau of Mines IC9183. Eger, P., Lapakko, K. 1989. The use of wetlands to remove nickel and copper from mine drainage. In Constructed Wetlands for Wastewater Treatment (June 13-17, 1988, Chattanooga, Tennessee). Hammer, D. A. (Ed), Lewis Publishers, Chelsea, MI. p. 780-787.
	Laboratory	Lapakko, K., Eger, P. 1981. Trace metal removal from mining stockpile runoff using peat, wood chips, tailings, till, and zeolite. In Proc. 1981 Symposium on Surface Mining Hydrology, Sedimentology and Reclamation. Lexington, KY. p. 105-116. Lapakko, K., Eger, P. 1983. Passive treatment of sulfide stockpile runoff. In Proc. 1983 National Conference on Environmental Engineering, A. Medine and M. Anderson eds. ASCE, New York. p. 643-651. Lapakko, K., Strudell, J., Eger, A. 1986. Trace metal sequestration by peat, other organics, tailings, and soils: A literature review. (Final Report BuMines Contract J0205047). U.S.D.I. Bureau of Mines NTIS # PB 87-186144. 45 p. Lapakko, K., Eger, P. 1988. Trace metal removal from stockpile drainage by peat. In Proc. 1988 Mine Drainage and Surface Mine Reclamation Conference, April 19-21, 1988, Pittsburgh, PA. V. 1. Mine Water and Mine Waste. U.S.D.I. Bureau of Mines IC9183. p. 291-300.
	Small-scale Field	Eger, P. 1994. Wetland treatment for trace metal removal from mine drainage: the importance of aerobic and anaerobic processes. In Wat. Sci. Tech., Vol. 29, No. 4. p. 249-256. Eger, P., Wagner, J., Kassa, Z., Melchert, G. 1994. Metal removal in wetland treatment systems. Proc. International Land Reclamation and Mine Drainage Conference/Third International Conference on the Abatement of Acidic Drainage. Pittsburgh, PA, April 25-29, 1994.

Strategy	Study Scale	Reference
	Operational	Eger, P., Wagner, J., Melchert, G., 1996. The use of overland flow wetland treatment systems to remove nickel from neutral mine drainage. In Successes and Failures: Applying Research Results to Insure Reclamation Success. Proc. 13th National Meeting, Knoxville, TN, May 18-23, 1996. p.580-89 Eger, P., Wagner, J.,Melchert, G., 1997. The use of a peat/limestone system to treat acid rock drainage. Proc. Fourth International Conference on Acid Rock Drainage. Vancouver, B.C., Canada, May 31-June 6, 1997. p. 1195-1209 Eger, P., Melchert, G., Wagner, J. 1999. Using passive systems for mine closure–a good approach or a risky alternative. In Mining in a new era. CD-Rom. Society of Mining Engineers Annual Meeting, Denver, CO, March 1-3, 1999. Preprint 99-38.
Sulfate Reduction	Barrel tests	Eger, P. 1992. The use of sulfate reduction to remove metals from acid mine drainage. In Proc. 9th National Meeting ASSMR, Duluth, MN, June 14-18, 1992. p. 563-575. Eger, P. 1994. The use of sulfate reduction to remove metals from acid mine drainage. Proc. International Land Reclamation and Mine Drainage Conference / Third International Conference on the Abatement of Acidic Drainage. Pittsburgh, PA, April 25-29, 1994. p. 412. Eger, P., Wagner, J. 1995. Sulfate reduction for the treatment of acid mine drainage: Long term solution or short term fix? In Proceedings of Sudbury '95 - Mining and the Environment. May 28-June 1, 1995, Sudbury, Ontario, Canada. p. 515-524

A6.1.2. Constructed Wetlands

Compilation of this literature is not yet complete.

A6.1.3. Anoxic Limestone Drains

Compilation of this literature is not yet complete.

A6.2. Active Treatment Systems, summarized April 25, 2000

LTV Steel Dunka Mine, MN:

References:
1. LTV Steel Mining Company Dunka Mine, Updated Final Closure Plan, Rev. 4, Mar. 15, 1996.
2. Dunka Data Summary: 1976-1993, Draft, MN DNR, Div. of Minerals, March 15, 1995.

Inflow quality: pH generally neutral, occasional acidic drainage from Seeps 1 & 3, Ni = 1-20 mg/L, occassionally as high as 30 mg/L, Cu = 0-1 mg/L

Treatment process: Lime (CaO) is added to the water to bring the pH up to at least 10, creating base metal carbonate and/or sulfate precipitates. The precipitate is treated with both cationic and anionic flocculents to enhance settling. The water then passes into a plate type thickener. The flocculated solids settle to the bottom of the thickener and form a sludge which is pumped to a holding tank. From there, the sludge is pumped to a pressure filter where the solids are retained on a filter media forming a filter cake for disposal.

The filtrate is pumped back to the system for reprocessing. The clear water overflow from the plate thickener passes through a sand filter which serves as a final polishing step. The water then passes to a pH adjustment tank where a small amount of sulfuric acid is added to bring the pH back to the compliance level range of 6.5 to 8.5. In actuality, the pH is controlled to 7.0.

Capacity: Annual flow from EM8 (roughly 2/3 of flow) and Seeps 1, 3, & X = approximately 3 x 10^6 L/yr, which flows to a collection basin and into the treatment plant. Seep 1 flow first passes through a limestone/peat pretreatment system.

Cost estimeas: Operation = roughly $200,000/yr, Construction (equilization pond, pump stations, treatment plant) = $1,494,000

Other notes: LTV contact person - Jason Augenes, 218-225-4364

Eagle Mine:

Contact: Dan Scheppers, State of Colorado, Dept of Health, 303-692-3398

Inflow quality:

Treatment process used: Lime precipitation of heavy metals with recirculation of sludge

Capacity: 160 gpm treated on average

Cost estimates: Treatment plant run by the responsible party, therefore no figures available

Other notes:

Contact: Gene Taylor, Project Manager, EPA, 303-312-6536

Inflow quality:

Treatment process used:

Capacity:

Cost estimates:

Other notes:

Summitville:

Contact: Angus Campbell, State of Colorado, Dept of Health, 303-692-3385

Inflow quality: pH = 3-3.2, Cu up to 40 mg/L (these are the monitorining parameters), also contains Fe, Mn, Zn, and Al

Treatment process used: Hydrated lime precipitation process involving sludge recycle. Water enters a mixing tank that also receives lime (midpoint) and recycled sludge (bottom?). The mixture flows via gravity feed to a reactor and onto a 60' wide x 20' high thickener. A polymer is added to the flow just before the thickener to aid flocculation. Thickener

underflow, 7-9% solids, is recycled to the mixing tank. The remaining sludge goes through a filter press and is desposed of on site in cells constructed in open pits. The sludge meets TCLP limits and is not considered hazzardous. The small amount of NP provided by the sludge is considered beneficial to the entire system.

Capacity: The plant runs 24 hours a day during the summer months (approx. 9 month operating season). It consists of 2 "trains", each receiving 550 gal/min inflow and 100 gal/min sludge = 650 gal/min per train or 1300 gal/min total flow. From April 27 through November 12, 1999, they treated 262,996,843 gal of water.

Cost estimates: Operating costs approximately 2.5 million $/year. No good information on capital costs because they renovated an existing processing plant from the 1960's. Renovation consisted mainly of modifying existing tanks and plumbing for mixing and aeration capabilities etc.

Other notes: Most of this information is contained in an Annual Report, which he will send to me. Also, they will be testing several passive systems at Summitville this summer (a saturated organic limestone cell, zeolite system -actually done by a contractor-, and Aquafix). He will send information on these as well. He would like a copy of our report when it is completed.

Additional Contacts: Victor Ketalapper, EPA, 303-312-6578

Argo Tunnel:

Contact: Mary Scott, State of Colorado, Dept of Health, 303-692-3413

Inflow quality: pH = 2.8, Fe = 180 mg/L, Mn = 100 mg/L, Zn = 70 mg/L, Al = 25 mg/L, Cu = 7 mg/L, total load = 1200 lb metals/day

Treatment process used: Chemical precipitation using 50% NaOH, more expensive but easier to handle except for the fact that the entire system must be heated because the NaOH solution freezes at 54 °F. Originally intended for the plant to be fully automated but that hasn't worked out so far (since 1998). Crews have worked shifts twenty four hours a day since operation began.

Inflow enters a rapid mixing tank, where it is mixed with a 50% NaOH solution to elevate the pH to 9.9. Water then flows into an Infilco Degremont Process Tank, which is essentially two tanks stuck together. The first unit is the particle building tank where water is circulated to enhance particle interaction. A polymer and about 5% of the sludge (depending on flow, e.g. 200 gpm flow requires approx. 10 gpm sludge) from the clarifier are added here to improve flocculation. This product flows into the second unit, a 12' diameter clarification tank. Sludge from the bottom of this unit is 3-4% solids. Sludge is pumped to liquid sludge storage and onto a filter press (mechanical dewatering). The filter cake is roughly 16% solids and disposed of in a municipal landfill. They are looking at building an on-site sludge repository but that may be a couple years away yet.

Clarified water (top of the clarification unit) has low turbidity (approx. 0.2 ntu) but still contains about 1 mg/L Mn. Therefore it is run through a mixed media gravity filter, which decreases Mn to 0.2 mg/L. The pH of the water is then adjusted to 8 using CO_2.

Capacity: Average inflow is approximately 320 gpm, ranging from roughly 250 gpm during the winter months to 600 gpm during the spring thaw. They can handle up to 700 gpm on two drains (350 gpm each). However they only have about twelve hours worth of storage capacity in the event of a total shut down. On average they use 1000 gal/day of the 50% NaOH solution, producing 17 yd^3/day.

Cost estimates: Design = $1 million in engineering costs, capital = $1 million in equipment, construction = $3.8 million, operation = $1.2 million per year.

Other notes:

California Gulch Superfund Site, Leadville drainage:

Contact:	Mike Holm, EPA, 303-312-6607
Inflow quality:	pH ranges from 2.5 to 7, typical is 4-4.5
Treatment process used:	NaOH precipitation followed by pH adjustment using H_2SO_4. Sludge tends to fail TCLP and must be disposed of as hazardous waste. They are doing some testing of fixation compounds to bind metals so that the sludge can be disposed of as an industrial solid rather than hazardous waste.
Capacity:	Can treat up to 2000 gpm, typically treats 1500-1700 gpm. However, subsidence in the area is changing the hydrology and the flow from this tunnel is increasing.
Cost estimates:	Operation = $900,000 per year, Sludge disposal = $100,000 per year
Other notes:	Automated operation run by the Bureau of Reclamation. Treats drainage from one of the tunnels in California Gulch. They are also looking at options to treat contaminated surface water around Leadville. Additional research in the area of phytoremediation is being conducted on a field scale and looks promising (removes approximately 70% of metals if pH >5.5). EPA Tech Trends paper by Brad Littlepage and Duane Johnson will be entered in papyrus.
Additional Contacts:	Brad Littlepage, plant operator at 719-486-2035.

California Gulch Superfund Site, Yak Tunnel (Leadville):

Contact:	Mike Holm, EPA, 303-312-6607
Inflow quality:	pH ranges from 2.5 to 7, typical is 4-4.5
Treatment process used:	NaOH precipitation followed by pH adjustment using H_2SO_4.
Capacity:	2000 gpm maximum. However, flow from this tunnel is decreasing. Currently the plant operates 3-4 days per week, treating approximately 400 gpm.
Cost estimates:	
Other notes:	Manual operation run through a joint venture between Asarco and Resurrection Mining Companies. Treats drainage from the other California Gulch tunnel.
Additional Contacts:	Gary Slifica, Asarco, 719-486-1056,

Equity Silver:

Contact:	Billings 2000 Conference-CD ROM
Inflow quality:	Cu = 116 mg/L, Fe = 1340 mg/L, Zn = 154 mg/L
Treatment process used:	Lime
Capacity:	60 - 150 L/s, approximately 5000 tonnes lime
Cost estimates:	$1.2 million/year
Other notes:	

Contact:	Aziz & Ferguson, Van97, V1, pg 181
Inflow quality:	average pH = 2.62, acidity = 8180 mg/L, Cu = 116 mg/L, Fe = 1340 mg/L, Zn = 154 mg/L
Treatment process used:	'ARD collection ditches flow into two collection ponds. The upper pond was designed for extra storage during high flow periods. The lower pond has a pumphouse that can pump a maximum of 4850 USG/min. The ARD is normally pumped from this pond to a storage pond located beside the treatment plant, but a portion of the flow can also be pumped directly to the plant for processing. Neutralization is achieved by adding quick lime slurry to a pH between 8.0 to 8.5. The ARD and lime slurry are combined in the first of three reaction tanks in series with a combined retention time of 20 minutes. Constant agitation is required to ensure maximum lime efficiency. The third reaction tank contains pH probes that control the addition of thelime slurry. Maximum plant throughput is 2150 gal/min. From the treatment plant the neutralized slurry is discharged to settling ponds where the metals drop out as a metal hydroxide sludge and the treated

supernatant decants to aholding pond. During the freshet period when regional creeks are at their maximum flows the treated water is released to the environment using dilution ratios that are specificed in the Equity water permit. The ARD sludge is pumped to the Main Zone pit for long term storage.'

Capacity: 'Over the last nine years (pre-1997) the average volume of ARD collected and treated at Equity annually has been approximately 880,000 m^3. The lime required to treat this volume of ARD depends on the acidity, but has averaged 5,060 tonnes/yr.

Cost estimates: Altogether the annual cost of running the ARD collection and treatment system averages around $1.1 million of which the lime represents 70% of the cost.'

Other notes:

Contact: Bill Price, 250-847-7389

Inflow quality:

Treatment process used:

Capacity:

Cost estimates:

Other notes: sending annual report (4/19/00), he wants it returned to him
couldn't find annual report, will e-mail answers to questions (4/24/00)

APPENDIX 7

Annotated Bibliography of References
Additional Mitigative Strategies under Consideration

A7.1. Chemical Stabilization of Reactive Mine Wastes-Microencapsulation
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A7.1. Chemical Stabilization of Reactive Mine Wastes-Microencapsulation

Williams, B.C. et al. (1999) Demonstration of metals-fixation technologies on the Coeur d'Alene River, Idaho. TMW99, pg 707.

Abstract: A field demonstration program is ongoing to compare in situ metals-fixation and metals-removal technologies on the Coeur d'Alene River. The river banks and upland materials consist of fluvially-deposited mine wastes and natural sediments. Metal loading to the river results from erosion of the banks as well as seep discharge of pore waters from the river banks. The demonstration technologies solicited for this project are directed to address near-bank ground water that discharges to the river. The technologies demonstrated in the field include encapsulation with alumino-silicates, fixation by apatite mineralization, and phytobioremediation. The field test plots will be evaluated according to several performance factors, including a) reduction in metals leachability, b) soil fertility, c) chemical stability of the final phase, d) cost per volume or area, e) operation and maintenance requirements, f) performance or stability in freezing weather, and g) potential risk to riparian ecosystems. Final reports on results not yet completed.

A7.1.1. Phosphate

Roy, S.; Worral, F. (1999) Pyrite oxidation in coal-bearing strata - the use of P-blocking techniques. Sud99, V1, pg. 177.

Abstract: ...control of the source of AMD by prevention of pyrite oxidation could provide a permanent solution to the problem. Coating technologies using phosphates, acetyl acetone, lignin and sodium silicate, have recently been investigated by several authors. Evangelou et al., demonstrate coating pyrite with iron phosphate by applying a phosphate/hydrogen-peroxide solution decreases amount of pyrite available for oxidation. In this study we statistically optimize the concentration of solutions used to provide a durable Fe- phosphate coating. This procedure may then be used as a remediation technique or to study the diffusion rates of oxidizing fluids within coal strata.

Conca, J.; Wright, J.; Mockler, T.J. (1999) Phosphate-induced metal stabilization for the remediation of acid Mine drainage and heavy-metal contamination. Sud99, V3, pg. 1143.

Abstract: Phosphate-Induced Metal Stabilization (PIMS) stabilizes a wide range of metals by chemically binding them into new stable phosphate phases (apatite minerals) and other low-solubility phases. The apatite can be emplaced as a down gradient permeable reactive barrier, can be mixed in with contaminated soil or waste, or can be used as a liner. the metals sequestered in apatites form new minerals that have great durability and leach resistance significantly exceeding other chemically stabilized waste forms, because the apatite mineral structure is stable over a wide range of conditions, e.g., pH 2 to 12, up to 1000 °C, in aqueous and non aqueous phase liquids, and under disruptions such as earthquakes, ground subsidence or human intrusion, for geologically long time periods, i.e., millions of years. The reactions are fast, occurring in minutes. Experiments on Bunker Hill Superfund site soils and ground water evaluated the use of various materials as reactive barriers and soil amendments to remediate heavy metal contamination for acid Mine drainage. The most effective material was a new highly reactive form of the mineral apatite, Apatite II, developed especially for remediation applications. Apatite II was hundreds to thousands of times more effective than other types of apatite and phosphate rock, three different types of bone char, mixed valent

oxide iron fillings, granular activated charcoal (GAC), zeolites, peat moss, exchange resins, Nucon Nusorb and Mersorb-3, especially for U, Pb, Cd, and Zn. The removal of dissolved U from DOE Y-12 facility NT-1 ground water at Oak Ridge, TN was also investigated using various reactive materials including Apatite II. Apatite II was much more effective than all other materials at removing U, even in the presence of nitrate concentrations exceeding 11,000 ppm. There was no pH effect for Pb and U sorption, but there was a strong effect of solution pH on Zn and Cd sorption, reflecting different mechanisms. Uranium precipitated as autunite and Pb precipitated as pyromorphite. Zn and Cd mostly sorbed onto particles but also precipitated as hopeite, hydrocerrusite, zincite, otavite and other phases.

Jensen, R.; Sogue, A.; Schurman, S. 1999. Treating heavy metals in Mine soil and waste using Envirobond™ binder. TMW99. pg 743-474.

Abstract: This paper presents the results of the remediation of a former mining site in Central City, CO, one of the Clear Creek Superfund projects. The Envirobond™ binder was successfully deployed to solidify and stabilize 3000 tons of metals contaminated Mine waste and soils, reducing the toxicity level substantially below TCLP RCRA limits. Mine waste containing high levels of arsenic, lead, zinc, and mercury were treated with Envirobond™. Typical heavy construction equipment was used to incorporate the binder with the soil in 500-ton lifts. A large lay down area of 5000 sq. ft. was used to layer and mix all of the soil. Final cost of the treatment was much less than for standard industry solidification processes and was significantly less than offsite disposal options.

3688 US EPA (1999): Environbond™ Process: Rocky Mountain Remediation Services. Superfund Innovative Technology Evaluation, Demonstration Bulletin, July, EPA/540/MR-99/502.

Summary: Provides a quick overview of the technology and the Ohio EPA/US EPA small-scale field tests on industrial soils at the Crooksville/Roseville Pottery Area of Concern, Roseville, OH. Preliminary results provided, but without interpretation of their meaning.

Fytas, K.; Evangelou, B. (1998) Phosphate coating on pyrite to prevent acid Mine drainage. Internat. J. Surface Mining, Reclamation and Environment, 12, 101-104.

Summary: This paper presents a series of laboratory column experiments (coating and leaching) that confirm that iron phosphate coating can considerably reduce AMD. This coating controls the oxidation process of pyrite by stabilizing pH around 6-7 and by reducing both sulfate and total iron production by 75% and 98%, respectively. Optimal coating concentrations for columns of 5.7 cm diameter were 0.1 M H_2O_2, 0.4 M KH_2PO_4, and 0.2 M NaAc.

Georgopoulou, Z.J.; Fytas, K.; Soto, H.; Evangelou, B. (1995) Pyrrhotite coating to prevent oxidation. Sud95, V1, 7.

Abstract: This paper presents the results of a research project on phosphate coating of pyrrhotite to prevent oxidation. The first phase of this research project evaluated the new technology on a pyrrhotite tailings sample. A series mini-columns of 0.9 cm of diameter and big columns of 5.7 cm diameter filed with the tailings sample were treated with a coating solution composed of H_2O_2, KH_2PO_4 and NaAc. H_2O_2 oxidizes the pyrrhotite and produces ferric iron so that iron phosphate precipitates as a coating on pyrrhotite surfaces. Results so far have shown

that coating is complete and protects pyrrhotite from oxidation. Long term experiments are still in progress in order to test coating resistance over time.

Evangelou, V.P. (1994) Potential microencapsulation of pyrite by artificial inducement of $FePO_4$ coatings. Pitt94, V2, pg. 96-103.

Abstract: A novel coating methodology was developed to prevent pyrite oxidation in mining "waste." The mechanism of this coating technology involves leaching mining waste with a phosphate solution containing hydrogen peroxide; when this solution reaches pyrite surfaces, hydrogen peroxide oxidizes the surface portion of pyrite and releases ferric iron so that iron phosphate precipitates and forms a passive coating on pyritic surfaces. This study demonstrated that iron phosphate coatings on pyritic surfaces could be established with a solution containing as low as 10^{-4} M phosphate and 0.027 M H_2O_2 and that the iron phosphate coating could effectively protect pyrite from oxidizing further. Development of this coating methodology could mean solution to production of acid Mine drainage from certain types of Mine waste. Further investigations are being carried out to extend this methodology to practical use.

A7.1.2. Silicate

Fytas, K.; Bousquet, P.; Evangelou, B. 1999. Application of silicate coatings on pyrite to prevent acid mine drainage. Sud99. pg. 1199-1207.

Abstract: AMD is a serious environmental problem that preoccupies the Canadian Mineral Industry. Coating sulfide minerals with silicates is a new promising technology to reduce AMD. Pyrite is treated with a solution containing H_2O_2, sodium silicate and a buffering agent. H_2O_2 oxidizes a small part of pyrite producing ferric iron ions. These ions subsequently react with the silicate ions to produce ferric hydroxide silica that precipitates on the pyrite surface producing a passive coating. This silicate coating can protect the grains of pyrite from oxidation. This paper presents a series of experiments that confirm that silicate coating can considerably reduce AMD.

3672 Rybock, J.; Mitchell, P.; Wheaton, A.; Hopper, R. (1999): Silica microencapsulation: an innovative technology for the prevention and treatment of ARD. Proc. of the Randol Gold & Silver Forum '99. Denver, CO. May 12-14.

Summary: Use of KEECO product KB-1, a calcium/silica-based slurry, to treat acid drainage fro the Kellogg Tunnel of the Bunker Hill Mine, Kellogg, ID. KB-1 contains three major components.

1. pH adjuster that initiates precipitation of heavy metals
2. Condensation polymerization, chemisorbing metals into a 3-D structure composed of silica. These microscopic matrices contain no fissures of fractures, completely surround the metal precipitates and continue to strengthen with time. The bound metal precipitates are in the form of a fast-settling, sand-like product.
3. acts as a support structure for the pH adjuster and polymerizer components, increasing available surface area and maximizing reactivity.

3113 Vandiviere, M.M.; Evangelou, V.P. 1998. Comparative testing between conventional and microencapsulation approaches in controlling pyrite oxidation. J. Geochem. Exploration, 64, pg. 161-176.

Abstract: ...Pyrite microencapsulation, utilizing either phosphate or silica coatings, is a novel approach

for controlling AMD that is under development in our laboratory. Although under laboratory conditions these approaches have been shown to be very effective in controlling pyrite oxidation, testing under natural conditions for possible field application is necessary. We are monitoring an outdoor leaching column experiment to evaluate the performance of both conventional and microencapsulation approaches for controlling AMD. The experiment consists of control, limestone, phosphate, and silica treatments on mine spoil and tailing samples contained in leaching columns and set up in the field. Preliminary results indicate that, after a period of nineteen months in the field, application of microencapsulation and conventional approaches significantly reduced pyrite oxidation. Among the microencapsulation approaches used with the Mine spoil, the silica coatings seemed to be superior. The average leachate sample pH was 1.9 from the control, 2.1 from the limestone, 4.6 from the phosphate and 5.9 from the silica coatings. The results of these outdoor leaching experiments have shown that the application of silica coatings could offer an improved solution for the abatement of AMD. However, long-term monitoring and evaluation are still needed.

Zhang, Y.L.; Evangelou, V.P. (1998) Formation of ferric hydroxide-silica coatings on pyrite and its oxidation behavior. Soil Sci., 163, 1, 53-62.

Abstract: The objective of this study was to examine the feasibility of controlling pyrite oxidation in bench-scale studies by creating a ferric hydroxide-silica coating that would prevent either O_2 or FeIII from oxidizing pyrite further. Ferric hydroxide-silica coating formation involved leaching pyrite at room temperature using a 10 mm-id chromatographic column with a solution containing H_2O_2, NaOAc, and soluble silicate at a flow rate of 0.43 mL/min. The results of this bench-scale study show that formation of a ferric hydroxide-silica coating was induced on the pyrite surface and that it inhibited pyrite oxidation under acid conditions.

Maki, S.; Belzile, N.; Goldsack, D. 1997. Inhibition of pyrite oxidation by surface treatment. Van97, pg 1-5.

Abstract: ...In this study, samples of pyrite from two origins were examined in the presence of two different oxidizing agents: hydrogen peroxide and air. Oxidation was controlled using coating agents applied to the samples prior to the oxidation process. Acetyl acetone, humic acid, lignin, oxalic acid and sodium silicate were employed and the relative efficiencies were examined. Not much useful information about silicate coatings.

3647. Klean Earth Environmental Company (1800): Klean Earth Environmental Company. Sales Brochure.

3675 Chatham, W.H.; Svee, W.A. (1996): Evaluation of KEECO product KB-SEA to permanently fix arsenic and other heavy metals in mine tailings characteristic of southwest Montana. Phase 1: Sample characterization and batch stability tests. Montana Tech, University of Montana, Butte, MT. 56p.

Summary: The primary goal of the work described was to determine the capability of the KEECO product, KB-SEA, to permanently stabilize and immobilize arsenic in mine tailings and contaminated soils and prevent its migration in the ground water and surface water systems. Field tests were conducted on the Spring Hill tailings, approximately 3.5 miles SW of Helena, MT. Tailings were stabilized wrt arsenic at a 2% application rate and heavy metals at a 5% application rate. Microscopic analysis suggest that the chemical may coat sulfide crystal surfaces with surface films which may slow the migration of water and oxygen into the material.

A7.1.3. Organic Polymers

Chen, Y.; Belzile, N.; Goldsack, D.E. (1999) Passivation of pyrite oxidation by organic compounds. Sud99, V3, 1063.

Abstract: Several techniques have been developed and used to limit AMD and ARD resulting from the oxidation of sulfidic Mine wastes. Passivation involves the coating of particles or rock surfaces with a substance or a combination of substances, which render them impenetrable to oxidative attack. In this study, we have examined the effectiveness of two organic compounds used in the milling process on two types of pyrite with and without an iron oxide layer. Aqueous solutions of the two organic compounds, diethyletramine (DETA) and potassium amyl-xanthate (PAX) were tested separately and in combined solutions of various concentrations. The results clearly showed that a combined solution containing 0.4% (w/v) PAX and 0.6% DETA was the most effective and could reduce the oxidation of pyrite by more than 75%. When pyrite samples were preoxidized to form a thin iron oxide layer, the efficiency of the same passivating solution increased to 85%. The passivation mechanisms resulting from the combination of these two coating agents and the possible large-scale application of this technique will be briefly presented.

Maki, S.; Belzile, N.; Goldsack, D. (1995) Inhibition of pyrite oxidation by surface treatment. Sud95, V1, 1.

Abstract: The oxidation of pyrite can become a serious environmental problem if the cycle resulting in AMD is allowed to commence. There are a variety of techniques which are being employed to prevent, halt and remedy AMD. In this study, samples of pyrite from two origins were examined in the presence of two different oxidizing agents: hydrogen peroxide and air. Oxidation was controlled using coating agents applied to the samples prior to the oxidation process. Acetyl acetone, humic acid, lignin, oxalic acid and sodium silicate were employed and their relative efficiencies were examined. Possible reasoning for the different chemical interactions is provided.

Moskalyk, R.R. (1995) Development of a protective cover for Mine waste rock. Sud95, V1, 99.

Abstract: A comprehensive laboratory study examined the feasibility of developing an acceptable thin cover for sulfidic Mine waste rock to minimize the generation of AMD which is the largest single environmental problem facing the mining industry today. The front end of the two year project consisted of a preliminary literature search regarding mechanisms, preventive treatment, testing procedures and effluent treatment of sulfide bearing process wastes. The study focused on the environmental fixation of Mine waste rock while a complementary aspect involved the examination of reactive mill tailings in order to retard acid formation by means of selected surfactants.

Bench scale test work, employing controlled leaching columns, enabled a quantitative evaluation of several classes of commercial sealants to minimize AMD from Mine development rock upon cyclic exposure to air and water. Reactive tailings were mixed with surfactants then placed in a similar column with a shallow water cover. Qualitative test work was conducted in parallel to examine the structural integrity of selected surfactants applied to Mine rock exposed to seasonal variation, such as freeze-thaw effect. The results indicate that, in general, protective dry and thin covers applied to Mine waste rock and tailings were effective in reducing leaching and AMD formation. Aqueous sealants, such as ENVIROSEAL, show promise as a suitable leachate retardant to reduce acid generation when sulfide bearing mineral processing wastes are exposed to oxygen and moisture.

Adams, R.L.; Ninesteel, J.J.; Rauch, H.W. (1994) Laboratory testing of coatings for prevention of acid drainage in underground coal mines. Pitt94, V2, pg 218-225.

Abstract: Laboratory research has been conducted to develop tough chemical and mineral coatings for the prevention of AMD in unsubsided underground coal mines. Specially designed sprayed coatings have the potential for substituting for initial rock dusting, preventing AMD in unsubsided mines, and opening up more acid-producing coal reserves for mining. Fifteen liquid chemicals were sprayed onto acid-producing Mine rock samples for laboratory testing of coating durability in water tanks. Eight chemicals that passed the durability tests, and four of these were judged suitable for further tests. These four chemicals were mixed with water and apatite dust and sprayed on Mine rock samples for more tests involving short-term bubbler tank, soxhlet, and long-term bubbler tank procedures. Two coating types, for chemicals code named I and G, passed these tests. These two chemicals were then mixed with limestone dust and water and further tested as sprayed Mine rocks using the same testing procedures. These coatings also worked well in retarding AMD products. For most tests coating G (an epoxy resin) worked the best but is most expensive; coating I (a latex) worked second best. The optimum G and I limestone coatings are ones composed of a 10% (by volume) chemical to 90% water solution mixed as a slurry with 30% by weight of limestone dust. These two coatings are economical, durable, and should be tested in an underground Mine.

A7.2. Selective Handling of Reactive Mine Wastes

A7.2.1. Backfill Using Paste Technology

Helms, W.; Heinrich, D. (1997) Development of backfill material for minimizing acid mine drainage generation in abandoned underground mines. Van97, V3, pg 1251.

Abstract: After production ceased in 1990 at the Elbingerode pyrite mine in northern Germany, generation of acid mine drainage still takes place. Large amounts of acidic mine water with high iron and sulfate contents have to be pumped to surface and treated by neutralization with lime. For geomechanical reasons (prevention of subsidence over open stopes), but also for minimization of AMD generation, mine openings on upper levels are backfilled. For technical and economical reasons fly ash from coal fired power plants is used, which was tested with regard to mechanical, environmental and safety aspects before permission for use was given. The backfill slurry, which is prepared from fly ash, cement and water, is pumped from surface directly to the stopes, which are filled completely.

The project is accompanied by a research project, in which technical, environmental and economic aspects of backfilling abandoned (or active) underground mines for minimization of AMD generation are investigated. In a comprehensive laboratory program several backfill mixes from different binders (Portland cement, blast furnace cement, high alumina cement and fly ash binder) and aggregates (quartz sand, tailings) have been tested for their properties with special regard to curing under AMD attack. Several curing resp. test procedures have been developed: storage open to air, in 100% humidity, and under water resp. under acidic water; irrigation with water resp. acidic water; permeability tests with water resp. acidic water. Main parameters of interest were compression strength and permeability (kf-value) of the specimens after curing. It could be shown that backfill mixes resistant to AMD attack can be developed provided a suitable binder is used and the binder content is high enough. An economic alternative to expensive cements is the use of fly ash. Sufficient strength and low permeability can be achieved even without addition of cement or calcium hydroxide

(depending on type of the fly ash). The consistence of the fly ash-water slurry makes it suitable for hydraulic transportation. So far, the results of the laboratory tests have been confirmed by the experience during backfilling of the Elbingerode mine.

Dahlstrom, D.A. (1997) Disposal of fine tailings in the underground mine. Tmw97 pg 327

Abstract: The paper discusses the development of a new method for concentrating the tailings by removing around 50% more water than is achieved by conventional thickeners. By use of flocculation with the modern polyacrylamide flocculants at around a dilution of around 2 to 5 wt.% tailings solids, a much higher underflow solids concentration can be achieved which develops a very high underflow solids concentration which exhibits a "slump" (the high solids concentration does not seek its own level). Most tailings can probably be thickened by extracting 50% more of the water when flocculated by dilution to somewhere between 2 and 7 wt.% solid. Dilution can be achieved by pumping water from the clean surface of the thickener.

Because of the high solids content of the underflow, the slurry can be pumped by a high pressure pump for disposal either to the surface or underground mine. As 50% more water is removed, the fine solids do not rewet and will stay where placed.

Cincilla, W.A.; Landriault, D.A. Verburg, R. (1997) Application of paste technology to surface disposal of mineral wastes. Tmw97 pg 343.

Pt Abstract: This paper provides an overview of the history and evolution of paste production technology with an emphasis on its application in the development of innovative alternative surface tailings management strategies. The advantages of surface disposal schemes which employ paste technology are outlined with a focus on geotechnical, operational, environmental/permitting and closure/reclamation issues. In addition, a conceptual design for the surface disposal of paste produced from full-run mill tailings from an underground mining and milling operation (now in the pre-feasibility stage) is presented as a practical model of the potential this alternative strategy holds for improving both environmental and operational performance.

Ouellet, J. et al. (1998) Mechanical, Mineralogical and chemical characterization of a paste backfill. Tmw98 pg 139

Abstract: Mining backfill is now current practice in many mines. Along the years different practices have evolved in the industry. Hydraulic fills, rock fills and high density fills have been used for quite some time now. But more recently, paste backfill, is spreading in Canadian mines. It has been used by some Quebec mines for the last four years. This type of backfill is prepared from unclassified tailings and put in place as a high density slurry with cement content varying from 3 to 6% by weight. This technology seems to have significant advantages compared to conventional cemented hydraulic fills. Since the water content of the paste is reduced no dewatering systems is deemed necessary in the backfilled stopes. For a given cement ration, the achievable strength is better, due in part to a lower water/cement ratio than hydraulic fills. The need not to be classified, so more tailings are returned under ground, minimizing the amount of waste to manage on the surface. In the example treated here, the pilot plant trial tests predicted very good strength for this operation with a bonding agent mix of 60% Portland cement and 40% fly ash. Nevertheless, achievable strength at the

production stage had to be revised and when the first pillars were mined out exposing the backfill faces the performance was much less satisfactory than expected. Excessive dilution and instability of the backfill were observed. A drilling program was then implemented to collect in situ samples for laboratory testing. The results of triaxial compression tests on samples prepared from the drilling cores showed very little cohesion which contradicted with test results from initial control samples. Mechanical, chemical and microscopic testing of the core samples demonstrate the presence of a chemical alteration in the backfill.

Lord, E.R.F.; Liu, Y. (1998) Depositional and geotechnical characteristics of paste produced from oil sands tailings. Tmw98 pg 147

Abstract: Syncrude Canada is evaluating the potential of paste technology as an alternative method of fine tailings disposal. Fine tailings is pumped to a thickener vessel and flocculent added to promote rapid settling of the solids. The supernatant water released is returned to the bitumen separation process immediately and a settling basin is no long required. The thickener underflow (paste) is pumped to a disposal site where a 'solid' tailings deposit is formed. Depositional and geotechnical testing has been conducted on the paste produced from small scale batch and continuous thickener (2 m long x 300 mm diameter) tests. The tests consisted of depositing the paste into a 300 mm wide and 9 m long flume and monitoring the behavior. Samples were taken for strength (triaxial compression) and consolidation tests. The results are presented in the paper.

Gay, F.; Constantiner, D. (1998) Additives for improving paste backfill mixes. Tmw98 pg 159

Abstract: Paste backfill mixtures exhibit high water demands due to high surface area, mineralogical composition and state of dispersion of the fine particles. A reduced water content results in a loss of flow unless an additive is used to compensate. Several additives have been tested to determine the water reduction attainable while maintaining the same flow of a "model" paste backfill mixture without additives. In addition, the compressive strength of the low binder-content backfill mixtures was monitored. In these tests, the binder was composed of 90% slag and 10% Portland cement. The results show that specific additives can reduce the water requirements (2% to 28%) without sacrificing the original flow properties. Reducing the water content in the paste can significantly increase its compressive strength (5% to as much as 100%), as long as the additive type and amount does not cause excessive retardation.

Luppnow, D.J.; Dorman, S.A. (1998) The advantages of paste disposal of tailings in arid environments. Tmw98 pg 167

Abstract: Mineral deposits are often situated in environments where water is scarce or of a finite quantity. The disposal of tailings in paste form by means of a landfill operation is a relatively new and untried technology. The costs and risks associated with using paste disposal of tailings appear to be relatively high when compared to conventional tailings disposal. For site specific situations there is, however, merit in using this new technology. However, mine owners and operators need to be convinced that there will be a return on their investment, both during the operating life of the facility and after closure. This paper outlines some of the financial advantages related to water resources and water management, both during operation and post closure, of using paste disposal in arid and water deficient environments.

Chen, L.J.; Millette, D.G.; Annor, A. (1999) A new development in paste backfill technology. Tmw99 pg 159

Abstract: Pate backfill has been introduced and practiced in underground mines since the early 1980's by which the mill tailings are disposed in the mine openings to provide a competent ground support. However, the technology is still in its development. Current paste backfill systems are based on either filtration or a blending technique which both involve expensive equipment and high energy consumption which has led the mines to search for a cost-effective technology in recent years. Alternative approaches to the problem are now being developed whereby the full plant tailings can be made into a paste by a sedimentation and fluidization process. This new development demonstrates that a tailings paste can be produced simply by fluidizing the settled solids in a silo system. The fluidization mechanism, experimental system and pilot plant test results are described and presented in this paper.

Bernier, L.R.; Li, M.G.; Moerman, A. (1999) Effects of tailings and binder geochemistry on the physical strength of paste backfill. Sud99, V3, pg. 1113.

Abstract: Before implementation of paste backfill at Brunswick Mining Division (BMD), Noranda Inc., laboratory tests showed decreases in cured pasted strengths after 90 to 120 days of curing. This could imply a risk of premature underground failures of the backfilled paste. Such failures may lead to loss or dilution of ore in the secondary stopes nearby, and the failed material could oxidize, potentially leading to self-heating problems and even emission of sulfur dioxide gas. To find the causes for the strength reduction and to gather data for optimization of the paste recipe, the relationship between tailings/binder geochemistry and cured paste strengths was investigated. Changes in geochemistry and mineralogy of wax-sealed paste cylinders were studied at different curing intervals ranging from 7 to 180 days. It was found that two paste mixtures attained the 1 MPa target strength and outperformed the control paste mixture. Maximum strength was generally achieved upon 120 to 180 days of curing and strength losses occurred after that. Intensified secondary ettringite formation does not seem to have occurred as a result of internal sulfate attack for curing times up to 180 days. A moderate pulse of secondary ettringite formation was observed after 120 days of curing and was considered a cause for strength deterioration. White clusters of gypsum and minor ettringite were visible in a one year old cured paste sample that used 5% Type 10 cement as binder. Addition of cement to tailings has the effect of immobilizing metals which otherwise are easily dissolvable. Partial substitution of Type 10 cement with type F fly ash in the binder appears to improve the sulfate resistance of the resulting paste. Selective A1 dissolution seems to be an effective analytical technique for measuring low contents of ettringite in cemented paste.

Landriault, D.A.; Brown, R.E.; Counter, D.B. (2000) Paste backfill study for deep mining at Kidd Creek. CIM Bulletin, V93, No. 1036., pg. 156-161.

Abstract: Both high density slurry and paste backfill are considered as alternatives to the current cemented rock fill system used at Falconbridge's Kidd Creek Deep Level Mine. High density slurry, although possessing very little excess water, must be transported at or above a critical flow velocity to avoid sanding-out of distribution lines. Paste is defined as a tailings-based mixture which, when idle, does not bleed water. It has no critical flow velocity.

Through investigation into resource availability, cost effectiveness and rheology, the backfill method at Kidd Creek's Deep Level Mine is examined. Recommendations are made surrounding a change to paste backfilling and the investigative steps and results leading to the

conclusion are highlighted.

A7.2.2. In-situ Leaching of Metals

Compilation of this literature is not yet complete.

Table A7.2.1. Summary of information contained in paste-backfill literature.

Reference	Purpose			Laboratory Study					Field Study			
				Binders			Tests		Mine Type		Binders	
	Summary	Method	Case Study	Fly Ash	Cement	Slag	Mechan-ical[1]	Chemical[2]	Under-ground	Open Pit	Fly Ash	Cement
Cincilla et al., 1997	x									x		
Lupnow & Dorman, 1998	x											
Chen et al., 1999	x	x										
Dahlstrom 1997		x										
Ouellet et al., 1998		x					x	x	x		x	x
Lord & Liu, 1998		x					x					
Gay & Constantiner, 1998		x			x	x	x					
Bernier et al., 1999				x	x		x	x				
Helms & Heinrich, 1997		x	x	x	x		x	x	x		x	
Hockley et al., 1998			x						x			
Landriault et al., 2000			x						x			

[1]Mechanical tests include compression strength, permeability, etc.

[2]Chemical tests include resistance to acidic water, chemical alteration of the backfill, mineralogy, etc.

A7.3. Treatment of Acidic Drainage

A7.3.1. Porous Reactive Walls

A GEOCHEMICAL AND MINERALOGICAL INVESTIGATION OF POROUS REACTIVE WALLS FOR THE PREVENTION OF ACID MINE DRAINAGE.
Waybrant, K.R.; Blowes, D.W.; Ptacek, C.J.; Benner, S.G.
Van97, V4, pg 1643 (1997)

Summary

Porous reactive walls have the potential to remediate mine tailings impacted groundwater, and to prevent AMD and the release of dissolved metals. Two 14-month column experiments were conducted to assess the long-term reactivity of selected mixtures under simulated dynamic groundwater flow conditions in the lab. The influent water was simulated mine drainage water containing high concentrations of Fe and SO_4. The two columns contained different organic mixtures; leaf mulch and sawdust in one, leaf mulch, sawdust, sewage sludge and wood chips in the other. Similar results were obtained for both columns. Minimum rates of SO_4 removal ranged from 500 to 800 mmol/d/m^3. Iron concentrations decreased from 300-1200 mg/L to <0.01-220 mg/L after passing through the columns. Alkalinity increased from < 50 mg/L to between 300 and 1300 mg/L. The acid generating potential of the water was converted from acid producing to acid consuming after passing through the columns. The observed changes in SO_4 and Fe concentrations, and an apparent inverse relationship between Fe and H_2S concentrations, suggest sulfate reduction and metal sulfide precipitation reactions are occurring. Geochemical model calculations of mineral saturation indices and isolation of a secondary Fe-S phase through microscopic investigation, further indicate that the dominant process removing Fe is precipitation of this Fe-S phase. Based on the column experiments, a full scale porous reactive wall was designed and installed in August 1995 at an inactive mine site near Sudbury, ON. Sampling nine months after installation indicates that the reactive wall is converting the ground water from an acid producing potential of 8-46 meq/L to an acid consuming potential of 16-45 meq/L.