

**CHRISTOPH WELS, Ph.D., P.Geo.**

PRINCIPAL

**EDUCATION**

Ph.D., Hydrogeology, University of British Columbia, 1995  
Fellowship, Environmental & Soil Chemistry, Syracuse University, 1991  
M.Sc., Watershed Hydrology, Trent University, Ontario, 1989  
B.Sc., Environmental Sciences, Trent University (Freiburg University), 1985

**PROFESSIONAL REGISTRATION**

Professional Geoscientist, APEGBC  
Professional Geologist, APEGGA  
Licensed Geologist/Hydrogeologist, Washington State

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**EXPERIENCE****SUMMARY**

Christoph Wels has over 25 years of experience in: design & implementation of site investigations and monitoring of mine impacts on groundwater resources; the development of groundwater flow and solute transport models to study current impacts and to evaluate the effectiveness of remedial activities; the design of mine dewatering systems for open pit and underground workings; study of waste rock hydrology including physical characterization, field monitoring and numerical modeling of key processes (infiltration, internal air flow and seepage); and the design of engineered covers for waste rock and tailings using numerical modeling and field trials.

Christoph Wels has been a third-party reviewer of pre-feasibility investigations, permitting documents and technical studies of mining projects on behalf of government agencies, mining companies and other consulting firms for project in Canada (BC, YT, NWT, Labrador), USA, Australia, Germany and Chile.

Christoph Wels has written over 30 technical papers on seepage and groundwater movement, contaminant transport, cover design and mine closure planning and was the lead author for the BC MoE Groundwater Modeling Guidelines for the Resource Industry which are available at: [http://www.env.gov.bc.ca/wsd/plan\\_protect\\_sustain/groundwater/groundwater\\_modelling\\_guidelines\\_final-2012.pdf](http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/groundwater_modelling_guidelines_final-2012.pdf)

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**PROFESSIONAL HISTORY**

2011-present: Corporate Consultant, Robertson GeoConsultants Inc. (Canada)  
2001-2010: Principal, Robertson GeoConsultants Inc. (Canada)  
1995-2001: Senior Hydrogeologist, Robertson GeoConsultants Inc. (Canada)  
1989: Hydrogeologist, Chalk River Laboratories, AECL, Ontario  
1985-1986: Hydrochemist, Freiburg Municipality, Germany

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## PROJECT EXPERIENCE (SELECTED STUDIES)

### GROUNDWATER IMPACT & SEEPAGE CONTROL STUDIES

#### ***Las Tortolas Mill Site, Chile (2010-present) for Anglo American Chile (AACH)***

- Detailed site characterization program (drilling and installation of monitoring wells) to delineate the seepage plume downstream of the Main Dam of the Las Tortolas TSF and the El Bosque irrigation areas
- Develop and calibrate groundwater flow and solute transport models for two dams and the entire facility to assess future groundwater impacts and seepage interception options
- Design of seepage interception systems for the Muro Principal, Muro Oeste and the El Bosque areas

#### ***El Soldado Mine Site, Chile (2010-present) for Anglo American Chile (AACH)***

- Detailed site characterization program (drilling and installation of monitoring wells) to delineate the seepage plume from the El Torito TSF in the Estero de Cobre valley
- Develop and calibrate groundwater flow and solute transport models to assess future groundwater impacts and seepage interception options
- Design of seepage interception system for the El Torito TSF

#### ***Granites Gold Mine, Australia (2006 - present) for Newmont Australia***

- Complete detailed site characterization to evaluate impacts on local groundwater due to historic seepage from tailings storage facilities (paddock TSFs and backfilled open pits)
- Develop 3D groundwater flow and solute transport model to assess future migration of seepage plume at the Granites;
- Design & implement seepage recovery systems for GTD01/03 and Bunkers Hill TSFs

#### ***Faro Mine, Yukon Territory (2004 - 2009) for Deloitte Touche (Interim Receiver on behalf of Federal Government of Canada)***

- Assess acid rock drainage from waste rock piles and design seepage interception system
- Develop water & load balance model for Rose Creek Tailings Storage Facility
- Design groundwater interception system for impacted alluvial aquifer (using pumping tests and 3D MODFLOW model)

#### ***Faro Mine, Yukon Territory (2009 - present) for Yukon Government (Assessment & Abandoned Mines)***

- Technical Advisor for AAM on all hydrogeological aspects of Faro Mine Remediation Project
- Annual groundwater quality and SIS performance reviews
- Design & implementation of NFRC winter drilling program, including installation of seepage interception wells downgradient of Intermediate Dump (near rock drain)

### TAILING WATER BALANCE STUDIES

#### ***Steepbank and Millenium Mine, Ft McMurray, Alberta (2010 - 2014) for Suncor Energy Ltd.***

- Perform water balance studies to understand the drying and consolidation of polymerized mature fine tailings (TMFT) using laboratory and field tests
- Assist Suncor in planning and operation of its Tailings Reductions Operations (TRO)
- Assist Suncor in monitoring and management of monitoring data
- Optimize tailings management to reduce water losses and make-up requirements

#### ***El Abra Mine, Chile (2012) for ARCADIS (Freeport MacMoran)***

- Review and interpret tailings characterization program (laboratory)
- Predict tailings consolidation and seepage from tailings impoundment over life-of-mine (250 ktpd over 24 years)
- Review predictions of water make-up requirements for alternative tailings management options (thickened tailings vs sand-slimes splitting)

***Escondida Mine, Chile (2007 - 2009) for BHP Billiton***

- Review historic and proposed future tailings management for Laguna Seca TSF
- Design & implement a tailings characterization program (in-situ and laboratory)
- Develop and calibrate a water balance model for Laguna Seca TSF to assess water losses and make-up requirements
- Optimize tailings management to reduce water losses and make-up requirements

***Chuquicamata Mine, Chile (2001 - 2003) for Codelco***

- Review historic and proposed future tailings management for Tranque de Talabre
- Design & implement a tailings characterization program (in-situ and laboratory)
- Develop and calibrate a water balance model for Tranque de Talabre to assess water losses and make-up requirements
- Optimize tailings management to reduce water losses and make-up requirements

MINE CLOSURE PLANNING

***Myra Falls Mine, Vancouver Island (2013 - present) for Nyrstar***

- Design & implementation of a detailed hydrogeological site characterization program
- Design seepage interception system for Lynx TDF
- Develop site-wide water & load balance model
- Evaluate alternative closure scenarios from a hydrological, hydrogeological and geochemical viewpoint

***Rum Jungle Abandoned) Mine Site, Australia (2010 - present) for NT Dept. of Mines & Energy (Australia)***

- Design & implementation of a detailed hydrogeological site characterization (incl. drilling, well installations, and hydraulic testing)
- Groundwater flow and groundwater quality monitoring to assess impact of ARD on East Finnis River and local bedrock aquifer(s)
- Development of a 3D groundwater flow & solute transport model to assess current seepage conditions and contaminant loading to the East Finnis River and the local aquifer(s)
- Assessment of alternative closure strategies using the 3D groundwater flow & solute transport model

***Los Bronces & El Soldado Mines, Chile (2013 – 2014) for Anglo American Sur***

- Develop conceptual mine closure strategies for Los Bronces Mine and associated Las Tortolas tailings storage facility
- Develop conceptual mine closure strategies for El Soldado Mine
- Assess hydrological, hydrogeological and geochemical data gaps for mine closure planning for Los Bronces, Las Tortolas and El Soldado

***Mt Morgan (Abandoned) Mine Site, Australia (2003 - 2010) for Qld. Dept Natural Resources (Australia)***

- Design & implementation of a detailed hydrogeological site characterisation (incl. drilling, well installations, and hydraulic testing)
- Groundwater flow and groundwater quality monitoring to assess impact of ARD on Dee River and local aquifer
- Development of a 3D groundwater flow model to assess current seepage conditions and contaminant loading to the Dee River and the local aquifer(s)
- Assessment of alternative closure strategies using the 3D groundwater flow model

***Giant Mine, NWT (2001 - 2006) for SRK Canada and DIAND***

- Participation in “Hydrogeological Expert Meetings” to review and critique hydrogeological studies carried out at the Giant Underground Gold Mine prior to 2001;
- Participation in hydrogeological studies in support of the Arsenic Trioxide Management Study;
- Development of a 3D groundwater flow model (as senior supervisor) to assess current groundwater conditions at the Giant Underground Mine and to evaluate closure options (reflooding, partial reflooding etc.);

***Woodcutters Mine, Northern Territories, Australia (2000 - 2009) for Newmont Australia.***

- Hydrogeological field investigation (drilling) and design of a groundwater monitoring program
- Development of a 3D groundwater flow and transport model (using MODFLOW & MT3D) to assess reflooding of underground workings/open pit and post-closure groundwater quality
- Development of a 2D seepage model (using HYDRUS) to determine fate of seepage from waste rock pile
- Assistance in the development of closure criteria & post-closure monitoring

## THIRD-PARTY REVIEW

***Codelco Tailings Dam Review Panel, Chile (2016) for Codelco***

- Member of Review Panel for Codelco’s 3 large copper tailings dams (Talabre, Caren, and Ovejera TSF)
- Responsible for technical review of hydrogeological studies related to seepage and seepage mitigation at Talabre, Caren and Ovejera TSF
- Responsible for technical review of groundwater models developed for each TSF to assess seepage mitigation and contaminant transport in local aquifer(s)

***Ovejera Tailings Facility, Chile (2012-2014) for Codelco***

- Technical review of hydrogeological studies aimed at characterizing seepage from the Ovejera TSF into downstream groundwater system
- Technical review of field trials and groundwater modeling aimed at identifying and designing seepage control strategies (pump-back, clean water injection)
- Review of international groundwater quality standards for sulphate

***Goro Nickel Mine, New Caledonia (2012-2014) for Vale New Caledonia***

- Hydrogeology expert member of Technical Review Board advising VNC on
- Design, construction & operation of Kwe West Residue Storage Facility
- Design of Post-Kwe residue storage facility
- Seepage and contaminant transport in local (karst) hydrogeology

***McArthur River Mine, Northern Territory (2015) for NT Dept. of Mines & Energy (Australia)***

- Review of current groundwater impacts & groundwater management practices
- Review of hydrogeological aspects of Mine Closure Plan

**Red Chris Mine, Canada (2012-present) for Imperial Metals Mining**

- Independent third-party review of hydrogeological studies completed for permitting of the Red Chris mining project
- Member of Independent Engineering Review Panel (IERP) for Red Chris TSF

**Abandoned Mines in Yukon Territory, Canada (2011-present) for Dept. of Energy, Mines and Resources, Yukon Government**

- Technical advisor to the Yukon Government on hydrogeological issues related to care & maintenance and closure of abandoned mines in the Yukon Territory
- Review of technical studies on seepage mitigation and performance reviews of existing seepage interception systems at the Anvil Range Mining Complex (“Faro Mine”)

**Morrison Project, Canada (2011-2012) for BC Environmental Assessment Office**

- Independent third-party review of hydrogeological studies completed in support for BC EA of the Morrison mining project, including:
  - Hydrogeological baselines studies
  - Groundwater modeling to predict dewatering of open pit
  - Groundwater modeling to predict seepage and contaminant loading from proposed tailings storage facility, waste rock and backfilled pit (post-closure)

**Collahuasi Mine, Chile (2010-2014) for X-Strata, Anglo American, and Mitsui**

- Technical review of three groundwater models developed by Collahuasi’s consultants to predict future groundwater extraction from Coposa basin, Michincha basin and Rosario Pit
- Assess feasibility and risks of groundwater supply for mine expansion to 160 ktpd

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**SELECTED PUBLICATIONS**

Wels, C., Mackie, D., and Scibek, J. (2012). “Guidelines for Groundwater Modelling to Assess Impacts of Proposed Natural Resource Development Activities”. Prepared for the BC Ministry of Environment, Water Protection & Sustainability Branch, April 2012.

Wels., C., P.R. Ferguson, and M. Fawcett (2012), “Numerical Groundwater Flow Modeling at the historic Rum Jungle Mine Site, northern Australia”, In proceedings of Tailings and Mine Waste '12, Keystone, CO, USA, 15-17 October, 2012.

Ferguson, P., C. Wels, and M. Fawcett, 2011, “Current Groundwater Quality Conditions at the historic Rum Jungle mine site, Northern Territory (Australia)”, In proceedings of Tailings and Mine Waste '11, Vancouver, B.C., 6-9 November, 2011, pp. 709-719.

Wels, C. and R. Zapata, 2010, “Assessment of Tailings Seepage from In-pit Tailings Storage Facility Using a 3D Groundwater Flow Model”, Paper presented at Mine Closure 2010, June 2010, Santiago, Chile.

Zapata R. Wels, C. and J. Bourne 2010, “Assessment of Post-Closure Flooding of Potentially Acid-Generating (PAG) Waste Rock Backfilled into Bonanza Ledge Open Pit, Canada”, Paper presented at Mine Closure 2010, June 2010, Santiago, Chile.

Wels, C., Laura Findlater and Chris McCombe, 2009, “Contaminant Load Balance Study for Mount Morgan Mine, QLD, Australia”. Paper presented at Securing the Future and 8th ICARD, June 23-26, 2009, Skellefteå, Sweden.

Wels, C. and Laura-Lee Findlater, 2009, "Groundwater Modeling as a Tool for Closure Planning: Prediction of Zinc Transport for Alternative Cover Scenarios". Paper presented at Securing the Future and 8th ICARD, June 23-26, 2009, Skellefteå, Sweden.

Wels, C., Findlater, L., and C. McCombe, "Assessment of Groundwater Impacts at the Historic Mount Morgan Mine Site, Queensland, Australia. In proceedings of the 7<sup>th</sup> International Conference on Acid Rock Drainage, St Louis, MO, 26-30 March 2006.

Wels, C., Robertson A. MacG., Madariaga, P.M., 2004, "Water Recovery Study for Pampa Pabellon Tailings Impoundment, Collahuasi, Chile". In proceedings of the 11th Annual Conference on Tailings and Mine Waste, Vail, Colorado, USA, 10-13 October, 2004.

Wels, C., Findlater, L., Shaw, S. and Laurencont, T., 2004, "Mt Morgan Mine - A Case Study of ARD Impacted Groundwater". In proceedings of Mine Water 2004 - Process, Policy and Progress, Newcastle upon Tyne, United Kingdom, 20-24th September, 2004, pp. 235-245.

Wels, C. and Robertson, A. MacG, 2003, "Conceptual model for estimating water recovery in tailings". In proceedings of the 10th International Conference on Tailings and Mine Waste, Vail, Colorado, USA, 12-15 October, 2003, pp. 87-94.

O'Kane, M., and C. Wels, 2003, "Mine Waste Cover System Design – Linking Predicted Performance to Groundwater and Surface Water Impacts", In proceedings of the Sixth International Conference on Acid Rock Drainage, Cairns, Queensland, Australia, 14-17 July, 2003, pp. 341-350.

Shaw, S., Wels, C., Robertson, A., Fortin, S., and B. Walker, 2003, "Background characterization study of naturally occurring acid rock drainage in the Sangre de Cristo Mountains, Taos County, New Mexico", In proceedings of the Sixth International Conference on Acid Rock Drainage, Cairns, Queensland, Australia, 14-17 July, 2003, pp. 605-616.

Wels, C., Lefebvre, R., and A. Robertson, 2003. "An Overview of Prediction and Control of Air Flow in Acid-Generating Waste Rock Dumps", In proceedings of the Sixth International Conference on Acid Rock Drainage, Cairns, Queensland, Australia, 14-17 July, 2003, pp. 639-650.

Wels, C., 2002. "Use of Waterloo barrier in progressive reclamation of hydrocarbon plume", Proceedings of 55th Canadian Geotechnical and 3rd Joint IAHC-CNC and CGS Groundwater Specialty Conferences, Niagara Falls, pp. 537-544, October 20-23, 2002.

Wels, C., S. Fortin, and S. Loudon, 2002. "Assessment of store-and-release cover for Questa tailings facility, New Mexico", Proceedings of 9th International Conference on Tailings & Mine Waste, Fort Collins, pp. 459-468, January 27-30, 2002.

Wels, C., S. Loudon and S. Fortin, 2002. "Factors influencing net infiltration into mine rock piles at Questa Mine, New Mexico", Proceedings of 9th International Conference on Tailings & Mine Waste, Fort Collins, pp. 469-478, January 27-30, 2002.

Shaw, S., C. Wels, A. Robertson, and G. Lorinczi, 2002. "Physical and geochemical characterization of mine rock piles at the Questa Mine, New Mexico", Proceedings of 9th International Conference on Tailings & Mine Waste, Fort Collins, pp. 447-458, January 27-30, 2002.

Lefebvre, R., A. Lamontagne, C. Wels, and A. MacG. Robertson, 2002. "ARD production and water vapour transport at the Questa Mine, New Mexico", Proceedings of 9th International Conference on Tailings & Mine Waste, Fort Collins, pp. 479-488, January 27-30, 2002.

Wels, C., M. O'Kane, S. Fortin, and D. Christensen, 2001. "Infiltration Test Plot Study for Mine Rock Piles at Questa Mine, New Mexico", American Society for Surface Mining Society for Surface Mining and Reclamation, Albuquerque, New Mexico, pp. 195-209, June 3-7, 2001.

Wels, C., M. O'Kane, and S. Fortin 2001. "Assessment of water storage cover for Questa tailings facility, New Mexico", American Society for Surface Mining Society for Surface Mining and Reclamation, Albuquerque, New Mexico, pp. 500-513, June 3-7, 2001.

Wels, C., A. MacG. Robertson and A. T. Jakubick, 2000. "A Review of Dry Cover Placement on Extremely Weak, Compressible Tailings", CIM Bulletin 93 (1043): pp. 111-118. September 2000.

Wels, C., U. Barnekow, M. Haase, M. Exner and A. T. Jakubick, 2000. "A Case Study on Selfweight Consolidation of Uranium Tailings", Paper presented at Uranium 2000; Conference held September 9-15, 2000, Saskatoon, Saskatchewan.

Wels, C., S. Shaw and M. Royle, 2000. "A Case History of Intrinsic Remediation of Reactive Tailings Seepage for Questa Mine". Paper presented at the ICARD 2000 Conference, Proceedings Volume 1, pp. 441-458, May 2000, Denver, Colorado.

Wels, C. and A. MacG. Robertson, 1998. "Assessment and management of Risks relating to Covers for Metal Leaching and Acid Migration", Paper presented at the 5th Annual BC Metal Leaching/ARD Workshop, December 9 - 10th 1998, at Vancouver, BC.

Wels, C., L. Smith, and R.D. Beckie, 1997. "The Influence Of Surface Sorption On Dispersion In Parallel Plate Fractures" J. Contam. Hydrology 28:95-114.

Wels, C., L. Smith, and T.T. Vandergraaf, 1996. "The Influence Of Specific Surface Area On Transport Of Sorbing Solutes In Fractures: An Experimental Analyses", Water Resources Res. 32: 4943-4954.

Wels, C. and L. Smith, 1994. "Retardation Of Sorbing Solutes In Fractured Media", Water Resources Res. 30: 2547-2563.

Wels, C., R.J. Cornett, and B.D. LaZerte 1991. "Hydrograph Separation: Comparison Of Isotopic And Chemical Tracers", J. Hydrology 122:253-274.