



WDA Consultants Inc.

List of selected Project Highlights included for Field Work, Data Processing, Interpretation of Data, Gas Leakage and CO₂ Storage

□ Field Work

- Planning and supervision of drilling and installation of shallow and deep piezometers and remediation wells in Düsseldorf / Hilden, Germany [3]
- Planning and supervision of drilling and installation of shallow and deep piezometers at a reservoir site in the Town of Turner Valley, Alberta [4]
- Collection of chemical and isotope samples at various sites in America, Europe and Asia [5]

□ Data Processing

- 2D and 3D-mathematical models of groundwater flow in an industrial area in Düsseldorf-Hilden, Germany [7]
- Development of the hydrogeologic data base and evaluation system HydroDynamik [HD] [8]
- Soil contamination at the tank farm Trippelsberg at start and end of remediation, Düsseldorf, Germany [9]

□ Collection, Evaluation, and Interpretation of Groundwater-related Data

- Regional hydrogeological background study for a Deep CBM development prospect in West-Central Alberta [11]
- Evaluation of 35 years of groundwater data from a major gas plant and streamlining of the groundwater monitoring network by means of 2D-vertical flow modelling [12]
- Review of neighbouring SAGD and Oil Sands mining prospects [13]
- Review of Suncor's Oil Sands mining activity [14]
- Review of a SAGD prospect, Athabasca Oil Sands, Alberta [15]
- Compilation and evaluation of 20 years of hydrogeological data at a petroleum industry plant site [16]
- Research project on the field investigation and 2D-vertical mathematical modelling at key contaminated sites in Germany, for the Federal Department of the Environment (BMU; Umweltbundesamt) Berlin, Germany [17]
- Reason for cattle death at a pond near a compressor station, Sand Hills area, Saskatchewan [18]
- Report on the environmental effect of the Alberta Petroleum Industry; joint venture with Alberta Environment and the Alberta Cattle Commission [19]
- Investigation of a moving landslide in a permafrost area, triggered by an earthquake, Fort Smith, NWT [20]
- Tailings disposal into an arctic meromictic lake, Garrow Lake, Cornwallis Island, NWT [21]
- Dewatering of an arctic base metal mine in karstic rocks, Pine Point, NWT, with Cominco Ltd. [22]
- Dewatering and slope stability in a tropical lignite mine, Neyveli, Tamil Nadu, India [23]
- Independent investigation of the feasibility of a major landfill at Blackie, Alberta, for the disposal of urban and possibly industrial waste by BFI on behalf of the City of Calgary, Alberta [24]

□ Gas Leakage and CO₂ Storage

- GASSYS: a unique and accurate passive gas-sampling system for repeated sampling of gas in soil and ground water at multiple depths [26]
- CO₂ sequestration: determination of flow and leakage pathways to surface aquifers and to the surface [27]
- Correction of a third party risk analysis for drinking water reservoirs and water supply at the Town of Turner Valley, Alberta [28]

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List of Project Sheets for Field Work

- Planning and supervision of drilling and installation of shallow and deep piezometers and remediation wells in Düsseldorf / Hilden, Germany
- Planning and supervision of drilling and installation of shallow and deep piezometers at a reservoir site in the Town of Turner Valley, Alberta
- Collection of chemical and isotope samples at various sites in America, Europe and Asia

Planning and supervision of drilling and installation of shallow and deep piezometers and remediation wells in Düsseldorf / Hilden, Germany

Project Location:	Düsseldorf / Hilden, Germany
Client(s):	County of Mettmann
Date Completed:	1995 - 2010
Project Budget:	Approx. € 3,000,000



Installation of 2"-piezometer and 24"-remediation well

Project Summary

In the project area, five major sources for chlorinated hydrocarbons (CH) are present; two steelworks, two chemical plants, and one waste disposal site. In addition there are four smaller plant sites. During three project phases, 85 piezometers were installed to a depth of up to 90 m within unconsolidated and fractured rock. The client opted for a pump and treat remediation scheme catching 4 plumes with twelve 24" remediation wells with increasing screen depths arranged in 4 nests.

Services Provided

- * Planning, drilling, and testing of 85 2"-piezometers.
- * Preparation of RFPs
- * Selection of successful drilling companies.
- * Supervision of drilling and installation.
- * Conduct and interpretation of geological logging
- * Planning, supervision and interpretation of borehole geophysics
- * Planning, installation and testing of twelve 24"-remediation wells up to 35 m depth.
- * Sampling and chemical analyses of piezometer water and interpretation of results

Deliverables or Results

- * Piezometers and remediation wells were handed over to County of Mettmann together with test results, proper documentation, and recommendations.

Planning and supervision of drilling and installation of shallow and deep piezometers at a reservoir site in the Town of Turner Valley, Alberta

Project Location:	Town of Turner Valley, Alberta
Client(s):	Town of Turner Valley
Date Completed:	2007
Project Budget:	\$ 120,000



Installation of 2"-piezometers using sonic drill

Project Summary

The Town of Turner Valley started building two surface drinking water reservoirs into the slope of the Sheep River Valley. When the safety of the reservoirs was publicly questioned with respect to the drinking water chemistry and stability of the reservoir dams due to the probable occurrence of leakage in and out of these reservoirs the Town of Turner Valley commissioned the installation of a series of piezometer nests for hydraulic purposes and chemical sampling.

Services Provided

- * Planning, drilling, and testing of twenty 2"-piezometers (up to 26 m deep) in 5 nests.
- * Selection of drill type and drilling company.
- * Supervision of drilling and installation.
- * Conduct and interpretation of geological logging.
- * Determination of hydraulic conductivity by slug tests.
- * Preparation of a 420 page report documenting and evaluating the results of the field studies.

Deliverables or Results

- * Piezometers were handed over to the Town of Turner Valley together with a 420 page report containing test results, proper documentation, and recommendations.

Collection of chemical and isotope samples at various sites in America, Europe and Asia

Project Locations:	Alberta, NWT, India, and Germany
Client(s):	Cominco, County of Mettmann, Ocelot Energy Inc., KfW Bank, and others
Date Completed:	1973 to 2007
Project Budgets:	in excess of \$1,000,000



Taking water samples at a flowing borehole and a karst spring south of Great Slave Lake

Summary of projects

WDA has undertaken a large number of water sampling programs for inorganic, organic and isotope species in developed areas, the Arctic, at oil industry sites, under severe winter conditions, by means of zodiacs along wild rivers, and by helicopter and float planes. The chemical data were collected for major regional studies (i.e. Cominco) as well as for more local studies (i.e. Ocelot). Three major investigations were done expedition style without outside support. Several studies were done to outline the extent and flow directions of regional subsurface fluid flow systems.

Services Provided

- * Planning, and conduct of field projects.
- * Selection of analysis procedures and outside supervision of lab work in close cooperation with various laboratories.
- * Interpretation of chemical and isotope data.
- * Preparation of reports and publications.

Deliverables or Results

- * Reports for clients and preparation of publications if warranted by the client. Representation of clients at public hearings.
- * The isotope results of a regional study between the Peace River and Great Slave Lake were published in: Weyer, K.U., Krouse, H.R., and Horwood, W.C., 1979. Investigation of regional geohydrology south of Great Slave Lake, Canada, utilizing natural sulphur and hydrogen isotope variations. *Isotope Hydrology* 1978, Vol. 1, pp. 251-264, International Atomic Energy Agency, Vienna.

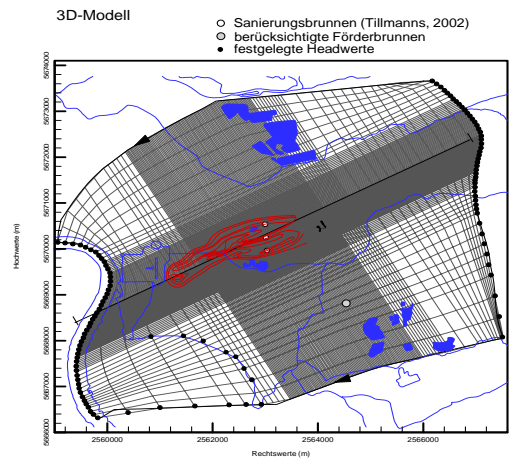
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List of Project Sheets for Data Processing

- 2D and 3D-mathematical models of groundwater flow in an industrial area in Düsseldorf-Hilden, Germany
- Development of the hydrogeologic data base and evaluation system HydroDynamik [HD]
- Soil contamination at the tank farm Trippelsberg at start and end of remediation, Düsseldorf, Germany

2D and 3D-mathematical models of groundwater flow in an industrial area in Düsseldorf-Hilden, Germany

Project Location:	Düsseldorf / Hilden, Germany
Client(s):	County of Mettmann
Date Completed:	2010
Project Budget:	exceeding 10,000 hours



Project Summary

3D-FE-model of groundwater and contaminant migration

In the project area, five major sources for chlorinated hydrocarbons (CH) are present; two steelworks, two chemical plants, and one waste disposal site. In addition there are four smaller plant sites. The goal of the project was to locate the sources for the contaminants, to determine their flow direction, and to devise a cost-efficient and effective remediation scheme to clean up the groundwater pollution. Regional dewatering of the Cologne Lignite mines (open pits up to 500 m deep) modified the natural groundwater flow and the migration of the CHC plumes significantly and these changes had to be taken into consideration. A series of vertical 2D- and 3D-FE-models and the use of the proprietary data evaluation system HYDRODYNAMIK enabled the complex flow lines in the different groundwater flow systems to be determined. The above model was then used to determine best locations and well design for a pump-and-treat system which is eventually to be replaced by enhanced and monitored natural attenuation. Dr. Weyer was in charge of the project alone and, at times, in conjunction with another consultant.

Services Provided

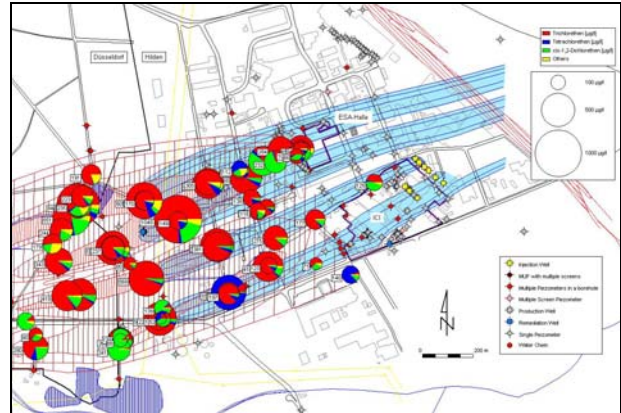
- * Development of a database encompassing over 1,000 piezometers and 20,000 chemical analyses.
- * Compilation and error checking of all relevant available data.
- * Conducted slugtests and chemical sampling for major ions, trace metals, CHC, and BTEX.
- * Determined the regional and local geology.
- * Ran a series of vertical 2D-FE-models to determine flow from shallow aquifers into the deeper karstic limestone aquifer, affected by regional mine dewatering.
- * Design and calculation of a 3D-FE model (app. 900,000 elements) for determination of groundwater flow and migration of contaminants by means of particle backtracking. Determined the most beneficial and cost-efficient number and location of wells, as well as pumping rates for remediation by pump-and-treat. These are to be used in the future to monitor the enhanced natural attenuation.

Deliverables or Results

- * All results were presented and included in a number of reports, some of them more than ten volumes (3000 pages) in size.
- * Design and installation of a hydraulic remediation scheme.

Development of the hydrogeologic data base and evaluation system HYDRODYNAMIK [HD] for efficient visualization and evaluation of field data

Project Location:	Calgary
Client(s):	self directed computer program development
Date Completed:	ongoing since 1995
Project Budget:	\$ 1,500,000



Capture zones of pump and treat wells (blue), pie diagrams of CH-contamination, and presumed plumes of dissolved Chlorinated Hydrocarbons (red hatching).

Project Summary

Hydrogeological and subsurface contamination investigations usually generate a flood of data, which may be difficult to document, visualize, and interpret, in particular if many years of historical data are also to be taken into account. When a large project required the determination of sources of CH-contamination in an area with six major industrial sites with altogether more than 1,000 piezometers, 100,000 water level readings, and 20,000 chemical analyses, it was decided to develop a novel kind of computer program for hydrogeological data evaluation. The program was intended to facilitate timely concept building based on all available data, permitting them to be accessible for inspection, in graphical and tabular form, at the click of a button.

The program HD closes the gap between field data and numerical models of the field site. It allows the hydrogeologist to formulate concepts directly based on the whole body of data present. HD has also been written in such a manner to facilitate, with error checking, the transfer of data from paper or distributed electronic form into a coherent electronic system.

The data encompass maps, borehole data, borehole geology data, borehole geophysical data, piezometer construction data, water level data, chemical data for water, soil and soil air, pumping data, and precipitation data. Cross-sections may be drawn and altered with a click of a button. All graphs may be printed in report ready format. HD has been successfully used at many large and small sites in Europe and North America.

Services Provided

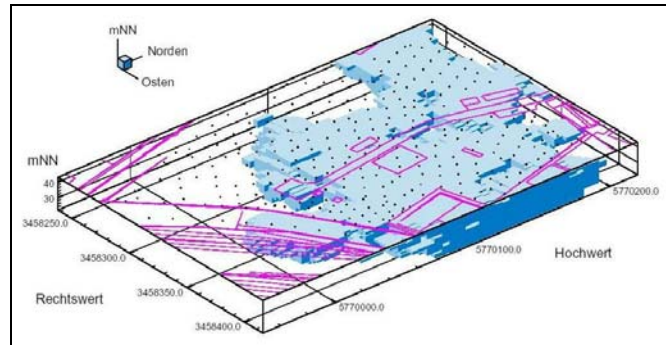
- * Development and case testing of the data visualization and evaluation program HD.

Deliverables or Results

- * Operational program HD.

Soil contamination at the tank farm Trippelsberg at start and end of remediation, Düsseldorf, Germany

Project Location:	Düsseldorf - Benrath, Germany
Client(s):	Deutsche Shell AG
Date Completed:	Phase 1: 2000; Phase 2: cancelled
Project Budget:	\$ 60,000



Tank farm Trippelsberg: Total hydrocarbon content in soil >500 mg/kg

Project Summary

As part of a contract for brown field development, the soil at the former tank farm Trippelsberg needed to be cleaned of hydrocarbons by enhanced bacterial action. A contract was awarded by Shell to document the soil pollution with hydrocarbons before commencement of remediation in phase 1, and upon successful remediation in phase 2, as required by regulatory agencies. In the first phase a database of soil contamination by hydrocarbons was developed and the various hydrocarbons (grouped by boiling point) plotted in 3D-plate-like structure and in some 2D-diagrams. The area affected is approximately 200 by 250 m in size.

The remediation has been delayed and phase 2 has been cancelled, having not been required by the regulatory agency.

Services Provided

- * Transfer of contamination data into a database.
- * Development of computer procedures to plot 2D- and 3D-distribution of soil contamination.
- * Preparation of report with text, 2D- and 3D-diagrams.

Deliverables or Results

- * Report with 2D and 3D distribution of soil contamination by hydrocarbons.

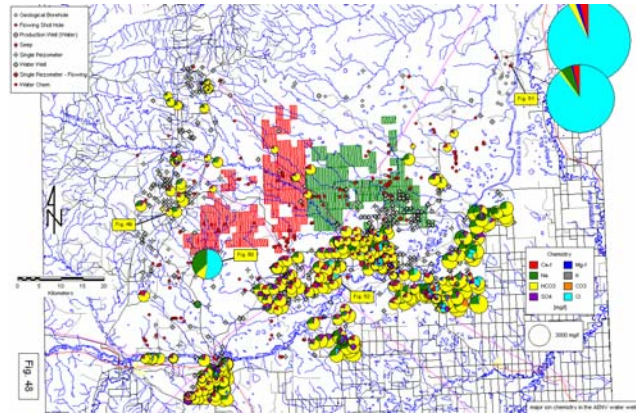
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List of Project Sheets for Collection, Evaluation, and Interpretation of Groundwater-related Data

- Regional hydrogeological background study for a Deep CBM development prospect in West-Central Alberta
- Evaluation of 35 years of groundwater data from a major gas plant and streamlining of the groundwater monitoring network by means of 2D-vertical flow modelling.
- Review of neighbouring SAGD and Oil Sands mining prospects
- Review of Suncor's Oil Sands mining activity
- Review of a SAGD prospect, Athabasca Oil Sands, Alberta
- Compilation and evaluation of 20 years of hydrogeological data at a petroleum industry plant site
- Research project on the field investigation and 2D-vertical mathematical modelling at key contaminated sites in Germany, for the Federal Department of the Environment (BMU; Umweltbundesamt) Berlin, Germany
- Reason for cattle death at a pond near a compressor station, Sand Hills area, Saskatchewan
- Report on the environmental effect of the Alberta Petroleum Industry; joint venture with Alberta Environment and the Alberta Cattle Commission
- Investigation of a moving landslide in a permafrost area, triggered by an earthquake, Fort Smith, NWT
- Tailings disposal into an arctic meromictic lake, Garrow Lake, Cornwallis Island, NWT
- Dewatering of an arctic base metal mine in karstic rocks, Pine Point, NWT, with Cominco Ltd.
- Dewatering and slope stability in a tropical lignite mine, Neyveli, Tamil Nadu, India
- Independent investigation of the feasibility of a major landfill at Blackie, Alberta, for the disposal of urban and possibly industrial waste by BFI on behalf of the City of Calgary, Alberta

Regional hydrogeological background study for a Deep CBM development prospect in West-Central Alberta

Project Location:	West-Central Alberta
Client(s):	Confidential
Date Completed:	2006
Project Budget:	\$ 75,000



Map showing major ion chemistry in water wells of AENV's Alberta Groundwater Database. Map: propr. program HD.

Project Summary

In the investigated area the depth of CBM wells exceeds 1000 m in places. Most of the wells are located within recharge areas and they reach into the domain of large regional groundwater flow systems. The regional flow systems will be somewhat modified by the necessary pumping of groundwater. The effect will, however, essentially not modify the discharge pattern of the regional flow systems as the produced water is reinjected into the Devonian Wabamun Formation, albeit at greater depth. Chemically, local and intermediate flow systems are characterized by bicarbonate water (yellow pie diagrams in figure above) while the regional system is dominated by chloride water (blue pie diagrams in figure above).

The coals are contained in about 300 m of sandstone-dominated layers. Above the sandstone sequence are about 500 m of a shale-dominated sequence. The presence of the shale sequence should ensure that the pumping activity at the CBM wells will not affect the operation of water supply wells for domestic and rural purposes, in terms of amount of groundwater flow and the occurrence of methane in the groundwater. That would be the case as long as proper seals have been installed in the annuli of CBM wells from the surface to the CBM coal layers, and as long as the annuli of conventional oil and gas wells in the area have been sealed in similar fashion.

Services Provided

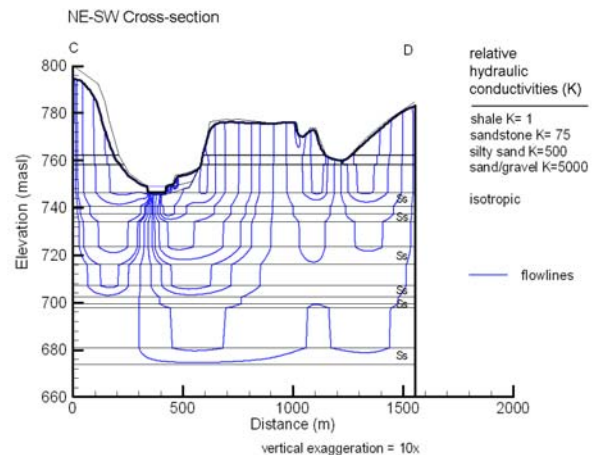
- * Assembly of a regional hydrogeological database using data supplied by the client and from the Alberta Groundwater database of Alberta Environment.
- * Evaluation of the hydrogeological database using the proprietary program system HYDRODYNAMIK [HD].
- * Investigation of groundwater flow systems in the area and their chemical fingerprints.

Deliverables or Results

- * Comprehensive report on the findings and the likelihood of disturbance to regional flow system and surface near water supplies by CBM production. The report contained 52 figures.

Evaluation of 35 years of groundwater data from a major gas plant and streamlining of the groundwater monitoring network by means of 2D-vertical flow modelling.

Project Location:	Central Alberta
Client(s):	Confidential
Date Completed:	2006
Project Budget:	\$ 55,000



Groundwater flow within a geologic cross-section.

Project Summary

The client had taken over the gas plant a short while previously and inherited confusing, incomplete and contradictory data depositories. Alberta Environment had imposed stringent conditions which had to be adhered to under time pressure, including the request for a simulation of groundwater flow at the plant site and towards a major River and one of its tributaries. All requests were answered within two months to the satisfaction of Alberta Environment.

Services Provided

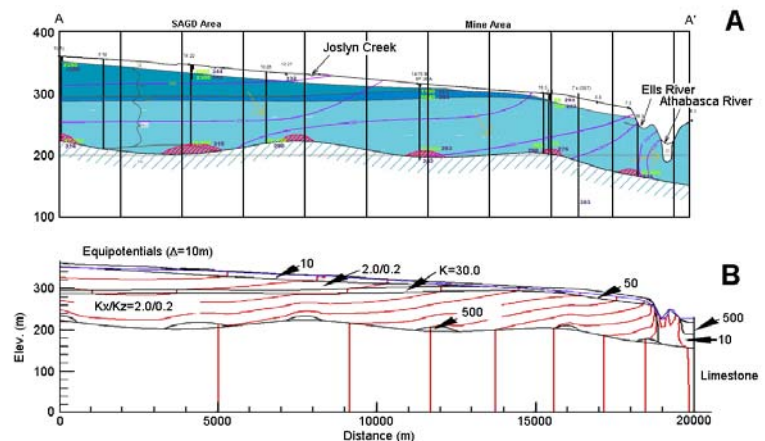
- * Error checking and creation of a hydrogeological database including all accessible groundwater dynamic and chemical data for the last 35 years. Evaluation of all data by means of the proprietary program system HYDRODYNAMIK [HD] and formation of a geologic concept for the calculation of 2D-vertical groundwater flow models in geologic cross-sections.
- * Streamline monitoring network by elimination of unnecessary piezometers and determine position and depth of new piezometers, based on the result of groundwater flow simulations in geological cross-sections (see figure above).
- * Determine, by means of the proprietary program system HYDRODYNAMIK [HD], background values for chemical parameters from data from the Alberta Groundwater Database.

Deliverables or Results

- * Submission of a comprehensive database to the client.
- * Report on the findings of the evaluation of the new hydrogeologic database and the results of the mathematical modelling of groundwater flow in geologic cross-sections.
- * Multiple successful presentations of plant site data, regional background data and the results of numerical groundwater flow modelling to Alberta Environment.

Review of neighbouring SAGD and Oil Sands mining prospects

Project Location:	Athabasca Oil Sands
Client(s):	Mikisew Cree First Nation
Date Completed:	2005, 2006
Project Budget:	\$ 45,000



Cross-section through the lease showing lateral equipotential lines within the Cretaceous oil sands. Profile A: Field measurements by the applicant. Profile B: Vertical 2D numerical model by WDA.

Project Summary

A number of development applications for SAGD (Steam Assisted Gravity Drainage) and mining development precipitated several reviews dealing, amongst other matters, with groundwater flow and chemistry patterns in the area under investigation. The lease is located close to the Athabasca River and in the vicinity of another application for mining. Both applicants made use of the same mathematical model for calculating groundwater flow and the effect and propagation of pressure changes due to mine dewatering and injection of fluids into the Basal Sands. The applicants' model is essentially a horizontal 2D model confined to the Basal Sands as the assumed regional aquifer. The model has restricted groundwater flow to the Quaternary and Cretaceous layers, considering the karstic Devonian limestone layers to be impermeable. The above cross-section A by the Applicant shows downward directed groundwater flow by means of lateral equipotential lines. The karst in the Devonian limestone was ignored during field investigation and in the applicants' mathematical model.

The review showed the widespread existence of limestone karst under the oil sands in the area of the lease by borehole records provided by the Applicant and by an evaluation of the surface of the Devonian rocks. The presence of karst immediately below the Cretaceous layers provides for effective pathways for pressure changes between injection and depressurization wells and for flow towards the Athabasca River. In addition the presence of permeable karst also affects the SAGD operation as pressure losses will occur into the Devonian karst. Therefore higher pressures likely need to be applied and the danger of surface escapes of steam is thus increased. Operating costs will increase as well.

Services Provided

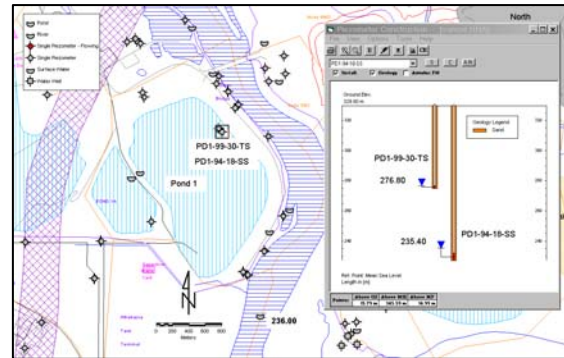
- * Creation of a hydrogeological database.
- * Evaluation of the hydrogeological database by means of the proprietary program system HD.

Deliverables or Results

- * Several reports were prepared for the Mikisew Cree First Nation; the client then delivered these reports to Deer Creek Ltd., to Alberta Environment (AENV), and to the Alberta Energy and Utilities Board (EUB).

Review of Suncor's Oil Sands mining activity

Project Location:	Athabasca Oil Sands
Client(s):	Mikisew Cree First Nation
Date Completed:	2005, 2006
Project Budget:	\$ 75,000



Downward directed flow of recharged tailings fluids and precipitation trough tailings disposal area Pond 1. Diagram from the proprietary program HD.

Project Summary

A series of applications and a subsequent hearing led to the evaluation of Suncor's mining activity in the vicinity of the Athabasca River and the Steepbank River. Based on a limited amount of data, it was established that the hydrogeological concepts and mathematical models used for dewatering predictions and environmental assessment were derived from the unfounded assumption that groundwater flow was restricted to Quaternary and Cretaceous layers. The mathematical modelling code was applied to the basal sands only and relied on confining layers above and below the Basal Sands. It was also assumed that the Basal Sands were the important regional aquifer underlying the oil sands while in reality the Basal Sands are discontinuous. Based on these assumptions groundwater flow was considered to be of local extent only and any connection to the Athabasca River was assumed to be negligible.

The review established that Devonian karst layers directly underlie the oil sands and the Basal Sands. They constitute the regional aquifer and are connected to the Athabasca River and the Steepbank River. The necessary inclusion of the Devonian karst into the hydrogeology of the Athabasca Oil Sands amounts to a paradigm shift with respect to technical and environmental consideration of mining activities within the Athabasca Oil Sands.

Services Provided

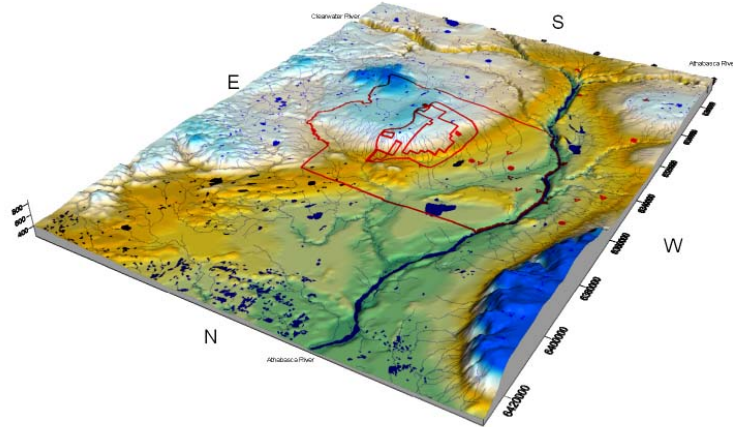
- * Creation of a hydrogeological database by determining and digitizing geological, water level and chemical data from diagrams in reports and applications of Suncor and its consultants.
- * Evaluation of the hydrogeological database by means of the proprietary program system HD.
- * Expert testimony at meetings and hearings.

Deliverables or Results

- * Several reports to the Mikisew Cree First Nation; the client then delivered these reports to Suncor Mines, to Alberta Environment (AENV), and to the Alberta Energy and Utilities Board (EUB).
- * Presentations to Suncor and their consultants, as well as to a hearing by the EUB.

Review of a SAGD prospect, Athabasca Oil Sands, Alberta

Project Location:	Athabasca Oil Sands
Client(s):	Mikisew Cree First Nation
Date Completed:	2004
Project Budget:	\$ 20,000



3D-Digital Elevation Model (DEM) of the principal development area, local and regional study areas for a SAGD prospect in the Athabasca Oil Sands.

Project Summary

Steam Assisted Gravity Drainage (SAGD) prospects typically have three hydrogeological components to them: water supply for the industrial and steam operation, injection of steam into the oil sand, and injection of waste water into the deep subsurface.

At several planned and existing prospects the water supply is taken from surface water; at the site under review water supply is to be from groundwater. Steam injection tends to create several significant changes to the groundwater regime, as i.e. higher pressure, higher temperature and increased permeability of the bitumen extracted oil sands layer. Within the area of the Athabasca Oil Sands, waste water is typically disposed of in the Cretaceous Basal Sands or into Devonian limestone. At the proposed site waste water will be injected into Devonian limestone layers.

Based on unfavorable drilling results the Applicant had planned to use injection pressures which effectively put the equivalent water head about 500 m above ground. The review recommended additional drilling to locate higher permeable zones. The additional drilling proved to be successful and the necessary injection pressure was reduced significantly such that the equivalent water head for the injection was below the ground surface.

Services Provided

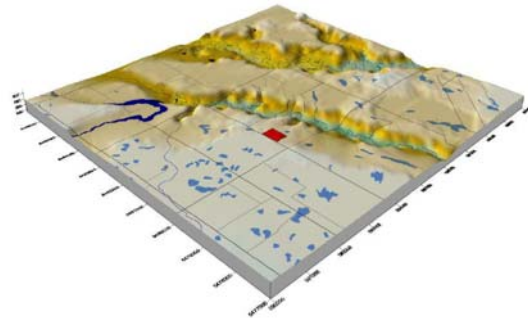
- * Evaluation of hydrogeologic data and expected pressure changes due to SAGD steam injection and waste water injection.

Deliverables or Results

- * Report on the findings of the review and recommendations derived.

Compilation and evaluation of 20 years of water level and chemical data at a plant site using the proprietary program HYDRODYNAMIK [HD]

Project Location:	Petroleum industry plant site in Saskatchewan
Client(s):	Confidential
Date Completed:	2005
Project Budget:	\$ 50,000



3D-Digital Elevation Model (DEM) of closer surroundings of plant site.

Project Summary

Typically, historical groundwater monitoring at petroleum plant sites has accumulated a wealth of annual monitoring reports and data often compiled by a variety of consultants. The reports are usually available as paper copies only and thereby excluded from modern evaluation techniques. Mining the data for particular day to day purposes is time consuming and thereby usually avoided.

A proprietary hydrogeological data documentation and evaluation program has been in development since 1995 to facilitate the transfer of data from paper or distributed electronic form into a coherent electronic system. This program made it possible for us to efficiently compile, error check, correct, document, and analyze twenty years worth of accumulated data. All data can now be accessed and visualized immediately.

Services Provided

- * Extracting all available data from paper reports and available spreadsheets.
- * Error checking all data by graphical display in construction diagrams of piezometers, on maps, on cross-sections, and within time series. Correct erroneous data for obvious and systemic errors. Documentation of all changes.
- * Compilation of a database for HD.
- * Preparation of an encompassing paper report, with all data contained in easily accessible tables and figures, and the evaluation of groundwater flow and associated migration pattern of dissolved constituents.

Deliverables or Results

- * Corrected data in electronic format.
- * Evaluation report containing all data in tables and diagrams.

Research project on the field investigation and 2D-vertical mathematical modelling at key contaminated sites in Germany

Project Location:	Research Project, Germany
Client(s):	Umweltbundesamt, Berlin (German EPA)
Date Completed:	1996
Project Budget:	DM 155,000

Project Summary

Traditionally, contamination studies concern themselves primarily with the occurrence and chemical changes of contaminants. The direction of groundwater flow is often ignored and assumed to be lateral, parallel to the groundwater table. This is the reason many groundwater monitoring designs spend large amounts of money unnecessarily on piezometer construction and chemical sampling.

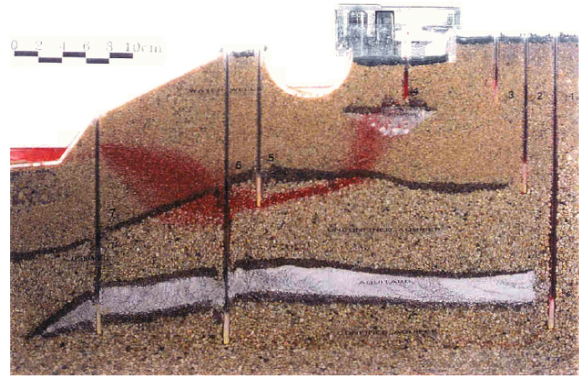
Within the above research project the physics of groundwater dynamics, including the flow through aquitards, has been dealt with in detail. Methods were developed to determine the extent of regional flow systems and their influence on local flow at contaminated sites. The methods were applied to the two main German pollution sites (similar in public impact to the Love Canal in the United States) and led to surprisingly different conclusions about the application of thorough and cost-efficient remediation measures. In both cases the applied remediation system proved to be mostly unnecessary due to hydraulic reasons, although more than about DM 10,000,000 had been spent on each site for so-called "remediation measures". At one site more than DM 1,000,000 had been spent upon unnecessarily repeated chemical analyses.

Services Provided

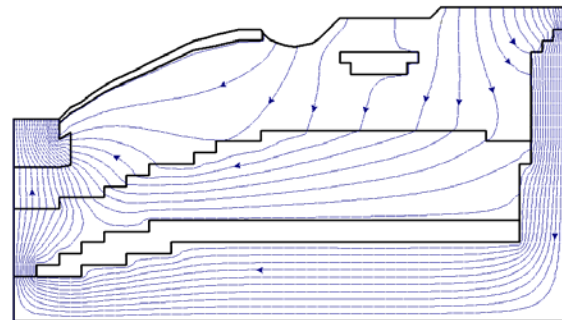
- * Treatise on the basics of groundwater dynamics as it applies to the migration of dissolved contaminants.
- * Application of available mathematical (2D-vertical) and sand models to visualize the vertical extent of groundwater flow systems and their influence on groundwater monitoring design.

Deliverables or Results

- * 205 page report on the effects of physically-consistent groundwater dynamics on the migration of dissolved contaminants [report in German].



Well defined plume of groundwater contamination (red) migrating towards creek from source of contaminants. Size of sand model 49 x 28 cm.



The corresponding flowlines in a simple vertical 2D mathematical model.

Reason for cattle death at a pond near a compressor station, Sand Hills area, Saskatchewan

Project Location:	Compressor Station in Saskatchewan, Canada
Client(s):	Confidential
Date Completed:	1995
Project Budget:	\$ 80,000



View from one of the dugouts towards the compressor station on the hill.

Project Summary

In the area of a compressor station and gas wells, eleven cattle, drinking from ice-covered dugouts, died within a time span of about 1.5 years. After a series of inconclusive investigations, this study was commissioned to determine the reason for the unusual deaths, which occurred only under the condition of ice-cover.

A detailed sampling program of water, gas and ice was devised to determine the organic, inorganic and isotope chemistry and radioactivity as well as the toxicity of the water sampled under winter conditions. The sampling successfully retrieved all planned samples from eight sampling points. The samples were sent to six different laboratories in Alberta, Saskatchewan and California. The analyses and evaluation of the analyses took about three months.

Services Provided

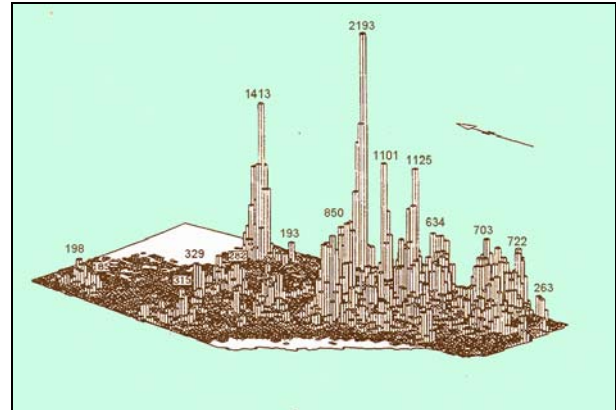
- * Design and undertaking of an expedition-style three day sampling program under extreme winter conditions.
- * Organization and management of an in-time sample maintenance and shipping program to six labs in two countries and subsequent supervision of chemical and toxicological analyses at labs within Calgary.
- * Preparation of a two volume detailed evaluation of the chemical and toxic conditions at the three dugouts.

Deliverables or Results

- * Two volume detailed report with findings, conclusions, and recommendations.

Report on the environmental effect of the Alberta Petroleum Industry; joint venture with Alberta Environment and the Alberta Cattle Commission

Project Location:	Alberta
Client(s):	Alberta Cattle Commission
Date Completed:	1995
Project Budget:	\$ 90,000



Density of Petroleum Industry Wells in Alberta per 100 km² as of 1993.

Project Summary

Upon initiation by the Alberta Cattle Commission, a review of available international scientific literature and previous investigations within Alberta were undertaken in cooperation with the Vegreville Alberta Environmental Centre of Alberta Environment. A four person WDA team was responsible for all technical topics but for direct impact evaluation on cattle.

A 900 page report was prepared encompassing sources and chemistry of contaminants, contaminant pathways in air, water and soil, impact on cattle, impact reduction, as well as regulations and guidelines.

Services Provided

- * Search for and evaluation of international and national literature on the above topics.
- * Search for and evaluation of Alberta-specific consultant's reports and data on the above topics.
- * Calculation of a series of numerical models dealing with the effect of petroleum wells on groundwater flow.
- * Preparation of a summarizing report of findings and of a joint report of findings with Alberta Environment.

Deliverables or Results

- * preparation of a 900 page report summarizing all aspects of the impact of the petroleum industry on cattle raising in Alberta.

Investigation of a moving landslide in a permafrost area, triggered by an earthquake, Fort Smith, NWT

Project Location:	Ft. Smith, NWT
Client(s):	Government of NWT
Date Completed:	1986
Project Budget:	\$ 50,000



Immediate effect of the October 5, 1985 earthquake; split and downed trees and opening of a 50cm wide crack

Project Summary

Between Fall 1985 and Spring 1986 a number of strong earthquakes occurred in the Mackenzie Mountains approximately 700 km NW of Fort Smith. Unexpectedly, they exerted an effect on the landslide area in Fort Smith causing cracks to open and accelerated creeping movements in portions of the slide area. The landslide area is the discharge point of local and regional groundwater flow systems and contains permafrost in parts.

A contract was awarded by the Northwest Territories government to identify the effects the earthquakes exerted on the landslide area in general and the water intake slope in particular, to identify the mechanisms and local conditions creating these effects, to assess their significance in regard to a permanent solution of the ongoing landslide problem and to ensure that the safety of a number of upslope buildings and their inhabitants, as well as the water plant upslope of the moving part of the water supply slope, remained secured until a solution to the landslide problem was implemented.

Services Provided

- * Emergency field investigations in response to the earthquakes of October 5 and December 22, 1985 and at the beginning of December 1985 in response to sudden acceleration of creeping movements.
- * Supervise daily recording by town personnel of water levels in five piezometers and distance measurements and daily assessment of changes for warnings of upcoming slide failure.
- * Review of scientific literature regarding the known effects of earthquakes on landslide areas. Informal consultations with US and Canadian earthquake agencies.
- * Slug testing of three piezometers to determine the permeability of particular layers in the landslide area
- * Preparation and submission of a report on the findings.

Deliverables or Results

- * The safety of upslope buildings, water intake structure and water plant was secured during the course of the project.
- * Preparation of a report documenting and evaluating the effect of the earthquakes upon the landslide area and implications for landslide stabilization.

Tailings disposal into an arctic meromictic lake, Garrow Lake, Cornwallis Island, NWT

Project Location:	Garrow Lake, Cornwallis Island, NWT
Client(s):	Department of Fisheries and Oceans, Western Region
Date Completed:	1980
Project Budget:	\$ 20,000



Annual supply ship at Polaris Mine

Project Summary

Polaris Mine is the northernmost lead-zinc mine in the world. Its tailings disposal area is below the halocline in Garrow Lake, which is a meromictic lake with elevated temperatures of 7 to 10 °C. The natural water surface elevation of the lake is 6 masl. Towards the south the lake is connected by a creek to the nearby (500 m) Garrow Bay of the Arctic Ocean.

When drilling in the area of the mine, a 'fluid loss table' had been encountered well above the 0 °C isotherm possibly as a result of karstic limestone features. The configuration of the 'fluid loss table' had not, however, been established between the Garrow Lake on the one hand, and Garrow and Cominco Bays on the other. The results of two thermistore boreholes were inconclusive. Due to the elevated temperatures below the halocline, the depth of the 'fluid loss table' under the ridges between Garrow Lake and the Arctic Ocean can be expected to be much shallower than that at the mine site.

As there has been a lack of groundwater studies in the high Arctic, groundwater studies in Antarctica were reviewed. There, saline groundwater has been flowing through permafrost down to about -30 °C. In view of the above, Dr. Weyer concluded that there is a very high likelihood of subsurface fluid flow from Garrow Lake to the Arctic Ocean.

Services Provided

- Reconnaissance trip to Polaris Mine and Garrow Lake.
- Review of consultants reports on Polaris Mine and Garrow Lake (and other meromictic lakes) as well as Russian, Canadian and American literature of fluid flow through permafrost.
- Preparation of a review report on groundwater flow in Antarctica.
- Preparation and delivery of findings for Garrow Lake.

Deliverables or Results

- Review report on groundwater flow in the high Arctic.
- Conclusion that subsurface fluid flow is likely occurring between Garrow Lake and the Arctic Ocean.
- Recommendations for further investigations.

Dewatering of an arctic base metal mine in karstic rocks, Pine Point, NWT, with Cominco Ltd.

Project Location:	Pine Point Mines, Pine Point, NWT
Client(s):	Cominco Ltd.
Date Completed:	1980
Project Budget:	\$ 1,000,000



Dewatering, Pine Point Mines

Project Summary

From 1975 to 1985 Dr. Weyer was an Advisor to the NWT Water Board on matters dealing with Mining and Water. On the occasion of his initial visit to Pine Point Mines in November 1975, Dr. Weyer predicted the failure of the dewatering system for the spring recharge due to melting snow. When this occurred, the only operating pit was flooded. Subsequently Cominco Ltd. went into a joint project with the Hydrology Research Institute for Dr. Weyer to investigate the reasons for failure, to facilitate safe dewatering, and to determine possible environmental effects within Wood Buffalo National Park.

During the life of the project the regional and local nature of fractured system, karst systems and associated groundwater movements was successfully investigated, proposals for improved dewatering were delivered, and the effect of dewatering on the flow of karst springs and the probable effect on the nesting area of the Whooping Cranes was documented and evaluated.

Services Provided

- * Investigation of regional and local groundwater flow systems.
- * Investigation of the interdependence of groundwater flow and open pit dewatering.
- * Compilation of a hydrogeological and geological database for the mining area and its surroundings based in DIAND's database of exploration holes in the area.
- * Preparation of proposals for low cost and more efficient mine dewatering.
- * Preparation of a 3 volume report compiling the results of the project.

Deliverables or Results

- * Successfully determined the reasons for previous dewatering failure.
- * Proposed an improved dewatering scheme.
- * 3 volume report with compilation of results.

Dewatering and slope stability in a tropical lignite mine, Neyveli, Tamil Nadu, India

Project Location:	Neyveli, Tamil Nadu, South India
Client(s):	KfW Bankengruppe, Frankfurt (German Development Bank)
Date Completed:	1975
Project Budget:	\$ 40,000



Ground water discharged by submersible pumps.

Project Summary

The Neyveli Industrial Complex processes mined lignite. At the time of the study, lignite production was to be doubled with development capital provided by the German Government through KfW Bankengruppe. The significant extension of production and the associated increased speed of mining necessitated an assessment of concepts and methods hitherto applied in dewatering and excavating the mine.

By use of ground data and satellite imagery (ERTS E-1110-04334-7-01), it was determined that the mine pit was located in a large recharge area, while some of the future open pits were to be located in a major discharge area. The groundwater chemistry in the recharge area was dominated by lateritic weathering. Evaporation of groundwater at newly opened faces led to cementation of unconsolidated material by precipitation of Al and Fe minerals within hours of mining the face. This caused problems for the operation of bucket wheel excavators and additional special mining equipment had to be applied.

Services Provided

- * Hydrochemical and hydrodynamic investigation of the mine proper and the wider surrounding area, based on available data, additional drilling, and evaluation of ERTS satellite imagery.
- * Determination of the reasons for the existence of unusually hard consistency and steep overburden slopes at the mining faces of the open pit walls

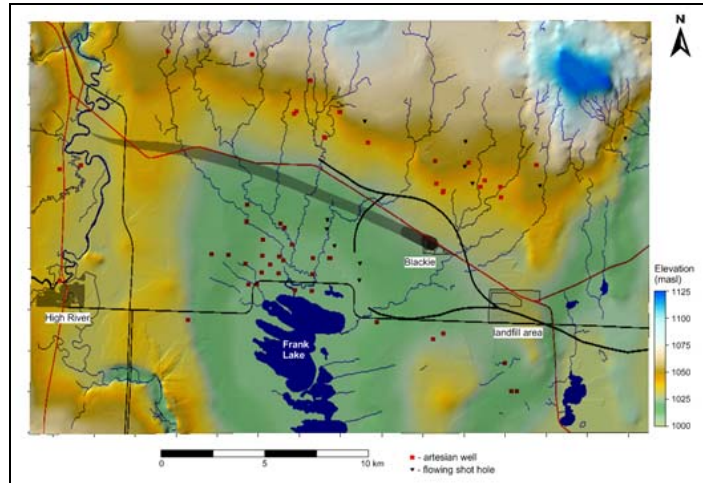
Deliverables or Results

- * Preparation of a report on findings with recommendations on groundwater-dependant improvement of mining within the existing open pit.
- * Recommendations on the soft consistency of mining faces in the newly planned open pits within the nearby groundwater discharge area. There, the chemistry of the groundwater was dominated by major ions. Evaporation of this groundwater at the open pit walls would not lead to cementation of the unconsolidated overburden. Hence a different set of mining equipment would have to be acquired for efficient mining of the new pit. Upon opening of the new open pit these predictions proved to be correct.

Independent investigation of the feasibility of a major landfill for the disposal of urban and possibly industrial waste by BFI on behalf of the City of Calgary, Alberta

Project Location:	Blackie, Alberta
Client(s):	Group of concerned citizens
Date Completed:	2012
Project Budget:	\$ 60,000

Medium scale DEM of the region under investigation. The landfill area is in the lower right quadrant of the map. The Town of Blackie is located southwest from there. It is the supposed endpoint of BFI's streamlined capture zone extending towards the west-northwest to the High River. Dots indicate flowing wells.



Project Summary

The City of Calgary is in need of additional landfill sites to dispose of an increasing amount of urban waste. BFI is the City's major contractor for waste disposal. Under the auspices of BFI a feasibility study had been done for a site close to the town of Blackie with favorable rail access to the nearby City of Calgary and to the United States towards the south. The hydrogeological part of the feasibility study showed some unusual results with respect to the capture area for the Blackie water supply. This capture area supposedly extended west-northwest more than 17 km to the High River, indicating this river to be the only source of water pumped at the Blackie water supply. WDA Consultants Inc. was hired to confirm or disprove BFI's hydrogeological concepts.

Services Provided

- * Collect and evaluate all geological and hydrogeological material publically available.
- * Evaluate all material provided by BFI.
- * Collect field data to support or reject the results of BFI's numerical model.
- * Document the occurrence of flowing wells and shot holes as indicators of discharge areas with upward flow.
- * Interview all owners of wells in the area as to the characteristics of their wells and drilling reports available.
- * Summarize all data and findings into an evaluation report.

Deliverables or Results

- * Preparation of a summarizing report entitled "Survey of groundwater in the Blackie Area, Alberta as impacted by the planned Prairie Sky landfill of BFI", 71 pages.
- * The report showed the hydrogeological concept and the geological evaluation of the natural clay layers supposedly underlying BFI's planned landfill site to be seriously flawed. The groundwater flow systems and the capture area of the Blackie water supply extend towards the north and possibly also in the direction of the planned landfill. The approval of the landfill was subsequently rejected by the Municipal District of Foothills No. 31.

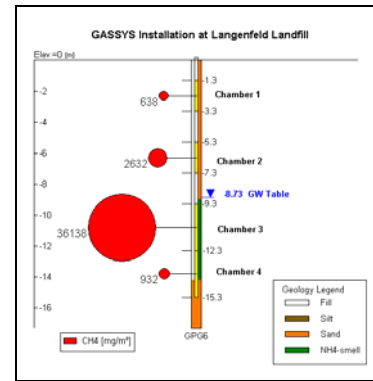
WDA Consultants Inc.

List of Project Sheets for Gas Leakage and CO₂ Storage

- GASSYS: a unique and accurate passive gas-sampling system for repeated sampling of gas in soil and ground water at multiple depths
- CO₂ sequestration: determination of flow and leakage pathways to surface aquifers and to the surface
- Correction of a third party risk analysis for drinking water reservoirs and water supply at the Town of Turner Valley, Alberta

GASSYS: a unique and accurate passive gas-sampling system for repeated sampling of gas in soil and ground water at multiple depths

Location:	Europe
Client(s):	Various clients with about 50 contamination sites
Date Completed:	1995 - ongoing
Project Budget:	Several projects



Left picture: Gas sampling system GASSYS with stainless steel tubing connected to four semipermeable chambers.
 Right picture: Methane measurements in a gas piezometer nest with four chambers at a landfill

Summary

Gas sampling serves three main purposes: (1) to determine production targets and possible safety risks (CO₂, CBM, SAGD), (2) to determine the location and concentration of vapours of contaminants for cleanup of soil air, and (3) for the repeated and accurate determination of soil gas and gas dissolved in groundwater for exploration and for natural attenuation at contamination sites. Methods used for purposes (1) and (2) usually are temporary installations and, most often, use some form of active pumping to extract the gas. Therefore gas is of mixed origin and their accuracy is approximate only. For a number of purposes these measurements are sufficient, as for example CBM and SAGD production, but not for investigations of natural attenuation.

The gas sampling system GASSYS is a permanent installation for long term repeated passive gas sampling under exactly the same conditions. The system collects the gas by diffusion into individual chambers with semipermeable membranes. GASSYS piezometer nests may contain up to 4 collection chambers to about 40 m depths within a special hose and the chambers may be installed above and below the groundwater table. For other purposes, the chamber material has been tested for underground use without failure for more than 20 years. A refined sampling and pressure recording system and protocol has been developed to ensure safe and reliable operation.

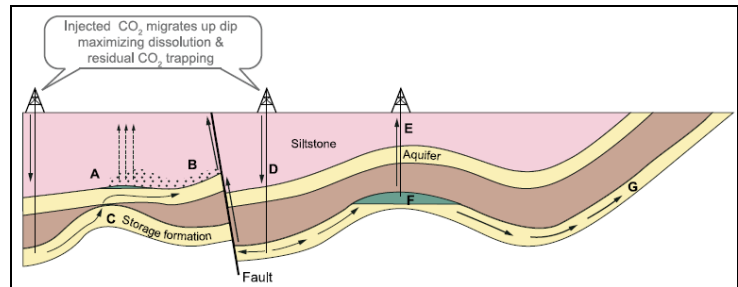
More detailed information is contained within our web site www.wda-consultants.com/gassys.htm, including a substantial list of gases GASSYS has been tested for. The system has been successfully used at landfills, uranium mining sites, contamination sites, pipe lines, plant sites, military sites (US-Army), etc. It may be used to determine leakage of natural or man-made gases to the surface (methane, etc) or along CBM boreholes and the like.

Services Provided

- * Input into the design, manufacturing and installation of gas sampling system GASSYS.
- * Initial or long-term drawing of gas samples, supervision of analyses and interpretation of results.
- * Training of personnel for clients.

CO₂ sequestration: Determination of flow and leakage pathways to surface aquifers and to the surface

Location:	Worldwide
Client(s):	various
Date Completed:	2008 - ongoing
Project Budget:	various



IPCC Special Report on Carbon Dioxide Capture and Storage, (2005 , Figure 5.25). The figure summarizes the concepts currently used.

Summary

Carbon Capture and Storage (CCS) is seen as the means to facilitate the shift from petroleum and coal-based energy to systems with no or greatly reduced CO₂ output. The Intergovernmental Panel on Climate Change (IPCC, 2005) made CCS the apparent method of choice to help reduce the rate of climate change while shifting to alternate energy sources. Subsequently, IPCC and Al Gore were awarded the 2007 Peace Nobel Prize for their work. Nevertheless there is a need to improve significantly on the concepts and physics used by IPCC (2005) for the planned injection and storage of CO₂.

IPCC (2005) adopted calculation methods widely used in reservoir engineering. There the subsurface movement of fluids (water, oil, gas, CO₂) is described in terms of pressure, buoyancy forces and caprock.

In September 2008, WDA was invited by PetroBras (a leading Brazilian petroleum company) to show what effect the application of a correct physics-based fluid dynamics would exert on the concepts presently prevailing in the risk-analysis of CO₂ storage. As an outcome it was shown that, in the on-shore subsurface, vertical buoyancy forces are rare and that they may even be directed vertically downwards (Buoyancy Reversal). The direction of CO₂ migration (as gas, supercritical fluid, or dissolved in saline aquifers) is determined in dependence upon force fields in groundwater flow systems. Caprock does not exist in the sense that it would be generally impermeable to movement of hydrous fluids. These and other conceptual and calculation changes are contained in www.wda-consultants.com/co2-main.htm

Services Provided

- * WDA provides to governmental agencies and the petroleum and coal industry advice to change present concepts to a physics-based injection planning of CO₂.
- * WDA provides advice in undertaking realistic risk analysis with respect to migration pathways, amounts and velocity of CO₂ seepage and leakage from the injection site to shallow aquifers and to the surface.
- * WDA offers the long term gas sampling system GASSYS for long-term monitoring of CO₂ seepage to the surface.
- * WDA helps in redesigning existing simulator codes to take the hydrodynamic pressure potential forces properly into account, thus eliminating the use of vertical buoyancy forces.

Correction of a third party risk analysis for drinking water reservoirs and water supply at the Town of Turner Valley, Alberta

Project Locations:	Town of Turner Valley
Client(s):	Alberta Environmental Review Board
Date Completed:	2008
Project Budget:	\$ 21,000



One of two water reservoirs for water supply of the Town of Turner Valley

Summary of project

For the purpose of the hearing of the Alberta Environmental Review Board an established third party had supplied to the Town of Turner Valley a simplistic risk analysis with the conclusion that the failure probability of the water supply system would be $3.78 \times 10^{-25}/\text{yr}$. In other words, the water supply system, including the reservoirs, was claimed to be totally foolproof under all conceivable conditions. WDA showed that the fault trees used did not reflect the systems installed, that the probabilities assigned to individual events did not reflect the realities at the site, and that the third party neglected the role of common events in calculating the failure probabilities. WDA determined the failure probability to be in the order of $4 \times 10^{-5}/\text{yr}$. The Board subsequently rejected the third party report.

Similar evaluation services can be applied to CO₂ storage.

Services Provided

- * By more realistic determination of individual failure probabilities and by inclusion of common events (taken from the nuclear industry) the third party's fault tree was recalculated and shown to be overly optimistic by far.
- * WDA can provide similar advice in subsurface storage (CO₂ and other fluids) with respect to building realistic fault trees and realistic estimation of failure probabilities.

Deliverables or Results

- * Submission of a report.