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PORTFOLIO AND PhD OPPORTUNITIES FROM USQ GROUNDWATER RESEARCH GROUP* Part II

Topic 14: Bioremediation of contaminated Water, Soils, Sediments, Sludges and Mining Residuals

Bioremediation (phytoremediation, bioventing, bioleaching, land farming, bioreactor, composting, bioaugmentation, rhizofiltration, and biostimulation) is the use of microorganism metabolism to remove pollutants. Technologies can be generally classified as in-situ or ex-situ. In-situ bioremediation involves treating the contaminated material such as soil, sediments, water, mining sludges, mining wastes, at the site, while ex-situ involves the removal of the contaminated material to be treated elsewhere.

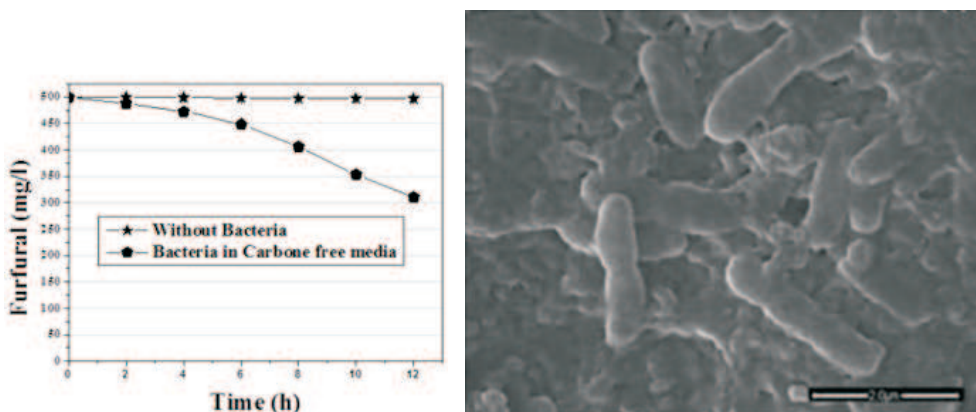
Bioremediation can occur on its own (natural attenuation or intrinsic bioremediation) or can be spurred on via the addition of fertilizers to increase the bioavailability within the medium (biostimulation). Recent advancements have also proven successful via the addition of matched microbe strains to the medium to enhance the resident microbe population's ability to break down contaminants. Microorganisms used to perform the function of bioremediation are known as bioremediators.

The contaminated media are easily treated by bioremediation using microorganisms. However, some elements are very difficult to remove from water and soil. For example, heavy metals such as cadmium and lead are not readily absorbed or captured by microorganisms. The Biosurfactants (saponin, surfactin, rhamnolipid) can replace the chemical processes/technologies for contaminant removal from waste water and soil. The plant derived surfactants (example: saponin) consists a wide range of applications in metal removal process from water and soil.

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Phytoremediation is useful under these circumstances because natural plants or transgenic plants are able to bioaccumulate heavy metals and other toxins in their aboveground parts, which are then harvested. The harvested plant material can be used as biomass e.g. for biogas production. The heavy metals may be further concentrated during the incineration process and disposed or even recycled for industrial use. Our group is working effectively on the removal process of toxic element such as As, Cd, Pb, Mn, Zn etc. from waste water and contaminated soil, sediments, sludges, etc. using bacteria and biosurfactants (bacterial mediated: surfactin and plant derived surfactants: saponin,). Also our group has capability to remove the polluted hydrocarbon as for example BTEX or Furfural from industrial waste water using effective microbes (*Pseudomonas* sp.).

The potential PhD student will investigate the in-situ or ex-situ removal process of toxic elements and hydrocarbons on laboratory scale and contaminated sites using bacteria, fungi, algae and plants.



a – Furfural degradation by *Pseudomonas* sp. in presence of Suphala fertilizer in Refinery waste water from Indian Oil Corporation Haldia, India.

b – *Pseudomonas* sp.: An effective microbe for the removal of BTEX and Furfural.

Topic 15: Risk Assessment of Heavy Metals and Arsenic and from Mining

Understanding Mobilization, Bioavailability, and Remediation Options Contamination by heavy metals and the metalloid arsenic from historic and recent mining activities has been reported worldwide. It constitutes a principal anthropogenic source of contamination in the hydrosphere, pedosphere, atmosphere and biosphere, and may adversely affect human health.

Mining, on the other hand, does not only deliver the necessary resources to support technological advancement, but it also secures local and regional workplaces, thus contributing to social and economic development. At the same time, these activities are related to environmental risks, which include those related to residues rich in heavy metals and

arsenic. Negating risks in the past has led to major, and long term, pollution problems, including direct negative impact on human health. A better assessment of the processes related to heavy metal and arsenic contamination, mobilization, bioavailability and human exposure to these contaminants through the food chain, drinking water and inhalation from atmospheric dust and a close cooperation between academia, mining industries and regulatory authorities, will contribute significantly to better understanding and mitigation of the problem. This goal is the key challenge of this research area.

Research on heavy metal and arsenic mobilization, bioavailability, human exposure and mitigation in mining areas is very challenging and includes assessment of interactions at scales ranging from molecular bonding to sub-continental, speciation in inorganic and organic materials using a wide variety of advanced chemical and spectroscopic approaches, and increased understanding of the importance of microbes and other biota in the cycling of heavy metals and arsenic. Although much has been learned about heavy metals and arsenic in the environment, many questions remain not answered and the ability to predict the impacts of heavy metals and arsenic to hydrosphere, pedosphere and biosphere often remains elusive. Accordingly, innovative research that provides the opportunity for PhD students to perform research in a wide range of study subjects is both appropriate, timely and challenging will help advance this area.

These research areas address the challenges of safe disposal of heavy metals and arsenic rich residues from mining activities. By using inter- and multi-disciplinary approaches, the research shall focus on the contamination of different environments such as water resources, sediments, soil, atmospheric dust by heavy metals and arsenic and the bioavailability from these to plants and animals, which allows these contaminants to enter into the human food chain. The last forms, together with exposure to heavy metals and arsenic by contaminated drinking water and inhalation of heavy metal and arsenic rich atmospheric dust, the principal exposure pathways to humans being of eminent scientific and/or public concern and with global significance. State-of-the art remediation and restoration tools of mining areas contaminated by heavy metals and arsenic and future directions in arsenic research related to mining areas are also targeted.

Research may be, but is not limited to, the following major themes:

- Source characterization of heavy metals and arsenic from mining, smelting, other mining related industrial activities,
- Dynamics of heavy metals and arsenic in soil, water and biota,
- Bioavailability/bioaccessibility in risk assessment and decision making,
- Treatment techniques and remediation methods for heavy metal and arsenic removal from water, sediment and soil,
- Reclamation of mining sites,
- Sustainability of safe water supply,
- Regulation and legislation,
- Prediction and modelling of the fate of heavy metals and arsenic in the environment,
- Speciation studies,

- Impacts of heavy metals and arsenic on agriculture and the food chain,
- Managing heavy metal and arsenic in contaminated soil and groundwater systems.



Our research in northern Taiwan: Acid mine drainage from Chinkuashi gold mine (photo: J.-S. Jean).



Our study area in Popoo Basin, Bolivia where extensive sulfide ore mining led to severe contamination. The photo shows the area of the mining town Oruro.

Topic 16: Geothermal Arsenic

Most geothermal fluids are rich in dissolved arsenic (As) and concentrations can be in the range of several to several tens of mg/L. However, little is known about the source, transport, speciation and fate of As, which all depend on geological, geochemical and physical conditions such as rock and mineral assemblage, redox potential, pH, pressure and temperature. In areas where geothermal fluids mix with groundwater or surface water bodies, which are used for human consumption, irrigation or other purposes, the geothermal As constitutes a natural hazard. This system, however, is complex and, often it remains unclear whether geothermal or anthropogenic As constitute the source. Determination of specific inorganic or microbiological assemblages or footprints (patterns) to identify geothermal As in these waters is therefore of importance.

Many measurements of As in geothermal fluids and cold groundwater in contact have been performed in the last decades, but practically none of the data are conclusive. Some data even is contradictory, likely due to insufficient sample densities and hence unsatisfactory statistical evidence.

The research where the potential PhD candidate would be participating will focus on major advancements and challenging issues, innovative developments and future perspectives of research on As in geothermal fluids and the interaction between these fluids and groundwater and seawater. It is a multidisciplinary scientific endeavour that is problem-driven with the aim to provide knowledge and understanding about the behaviour of As in terrestrial and submarine hydrothermal systems and the impact on the environment at or near the earth's surface. Our goal is taking a holistic approach to the interpretation of As behaviour in the subsurface, ranging from biological to thermodynamic approaches. Such new information in this area is necessary to understand the role geothermal As plays in the genesis of As-rich ground- and surface water resources, which are used for human consumption.

Our research also focuses on arsenic species in geothermal fluids, including those from terrestrial and submarine hydrothermal systems that reflect current thinking and awareness in that field that involves cutting edge science. The research will be focused on geochemical and biogeochemical processes related to arsenic in geothermal fluids and related environmental issues of scientific or public concern with global significance. Research provides an assessment of the state-of-the art and what are future directions in arsenic research related to geothermal fluids.

Research topics include but are not limited to:

I. Arsenic in geothermal fluids: occurrence, genesis, mobility, transport

- Sources of As in geothermal fluids: mineral phases present in different types of geothermal reservoirs (volcanic/non-volcanic, high-enthalpy/low-enthalpy, supercritical or not, marine/terrestrial).
- Solid-fluid phase interactions and As mobilization processes from solid mineral phases into geothermal fluids (within the geothermal reservoir and along pathway of uprising

geothermal fluids), As mobility controls, As speciation and the dependence on geological, geochemical and physical conditions such as, redox potential, pH, pressure and temperature.

- Geochemical and biogeochemical processes in the fluid and between solid and fluid phases, which are occurring along the pathway of ascending geothermal fluids and their relevance for altering the chemical fluid composition, the As contents and species composition. Differences of respective behaviour under adiabatic and non-adiabatic conditions.
- Hydrogeochemical modelling.

II. Identification of pattern to distinguish geothermal As from other As sources

- Using pattern of inorganic chemical and microbiological composition, the As source may be identified.

III. Interactions of geothermal fluids mixing with shallow ground- and surface water and related environmental and human exposure effects



Our research on geothermal arsenic in Mexico – geothermal reservoirs.

Topic 17: Geomicrobiology of toxic Trace Elements in aquatic Ecosystems

Toxic trace elements in the hydrosphere, mostly from natural geogenic sources, and their adverse health affects are a global problem. Advances of more sophisticated analytical instrumental methods coupled with new epidemiological studies of health impacts of toxic

trace elements (TTE) exposure have resulted in the reduction of guideline values for many of these elements in drinking water, irrigation water, soil and food. This lowering of the limits has greatly increased the global human population that is exposed to elevated levels of TTE. It is therefore timely to assemble a special issue concerning geomicrobiological processes that affect the behaviours of these elements at the interface of the geosphere, hydrosphere and biosphere. Geomicrobiological processes affect the mobilization, sequestration, and bio-availability of toxic trace elements (metals and metalloids) in groundwater aquifers, lakes, streams, estuaries, and other aquatic ecosystems.

This research area focuses on geomicrobiological processes of TTE of geogenic origin in aquatic ecosystems and the interface of these processes between the geosphere, hydrosphere and biosphere. Understanding geomicrobiological processes that may play a key role in the mobilization and transport of TTE is essential for understanding the potential ecotoxicological effects of these elements in the environment and primordial to mitigating its deleterious effects on ecological and human health. In some cases, understanding the interactions of TTE with microorganisms can lead to strategies for microbial-assisted removal of TTE from water and soil by in-situ or ex-situ methods of immobilization in aquifers and other water supplies.

Our research is a multidisciplinary scientific endeavour that is problem-driven. It aims assist society through providing knowledge to deepen the understanding of biogeochemical factors that affect the behaviour of TTE in the environment. Our research goal is a holistic approach to interpreting microbiological processes and interactions between different TTE. This includes pathways of predominantly geogenic trace metals, from their occurrence in rocks and minerals, subsequent release due to weathering and biogeochemical processes, and their sequestration or mobilization in the environment in response to geomicrobiological processes.

Biogeochemical processes which influence the bioavailability of TTE from water and soil to different plants, fish, animals, and humans through the food-chain are addressed. Such research is timely due to worldwide interest in TTE, which is accelerated by the lowering of limit values for many of them in drinking water, soil and food. The research includes mechanism- and process-oriented studies on accumulation of TTE in water, sediments, plants, animals, and humans. Accumulation of TTE and their bioavailability are influenced by interactions with abiotic and biotic environmental components. Bioavailability of TTE from water and sediment to flora, fauna, and humans is addressed in the context of biogeochemical interactions and other environmental parameters that may influence bio-availability.

Oxidative and reductive transformations of toxic trace metals and metalloids (including but not limited to As, Se, Cr, U, and Te) are often mediated by microorganisms as a mechanism of either detoxification or metabolic energy production. These microbiological processes can exert profound effects on the mobility, toxicity, and bioavailability of trace elements in aquatic ecosystems as well as their release to water sources that are used for human consumption and agricultural irrigation. In more hostile settings that are characterized

by extremes in temperature, salinity, pH, or toxicity, the microbiological cycling of trace elements can strongly influence the biogeochemical cycles of C, S, N and other major elements. An understanding of these geomicrobiological processes on both the cellular and ecosystem scale is critical to predicting the fate of toxic trace elements in contaminated settings and to elucidating novel metabolic processes whereby life can exist.

This research is aimed to address challenging issues in the biogeochemistry of TTE. Key topics are bench-scale studies of processes which drive release and transport of TTE into the hydrosphere thereby controlling their bioavailability and bioaccumulation, as well as field-scale studies that demonstrate the environmental effects of these processes. Interdisciplinary approaches and studies, including microbiology, environmental biochemistry, ecology and contaminant hydrology are primary focus.

Research topics for potential PhD candidates comprise but are not limited to:

I. Microbiological processes involving TTE at mineral-water interphase

- Microbiological dissolution of TTE from minerals

II. Microbiological processes affecting TTE mobility in aquifers and other water environments

- Enzymatic and cellular biochemistry of TTE oxidation and reduction
- Molecular biology studies of the genes responsible for metal reduction
- Process-oriented laboratory studies with TTE oxidizing/reducing bacteria

III. Microbiological processes in aqueous sediments and at the water-soil interphase

- Reductive release or sequestration of TTE by microbes in anoxic sedimentary pore water
- Release of adsorbed trace metals by reductive dissolution of Fe- and Mn-oxides
- Co-precipitation of TTE with sulphides and other biogenic minerals

IV. Microbiological processes at the geosphere-hydrosphere-biosphere interface

- Effects of microbiologically induced speciation changes on the bioavailability, bioaccumulation and toxicity of TTE in aquatic food webs
- Nutrient availability and other geochemical factors that affect rates of TTE cycling in aquatic ecosystems

V. Microbiological processes for TTE immobilization in aquifers and soils; removal of TTE from water

- Microbes for TTE removal from water
- Microbes for TTE immobilisation in aquifers

Topic 18: Fluoride Transport and Mobility Controls in Sedimentary Aquifers

In many regions, fluoride is a widely distributed constituent found in sedimentary porous aquifers, in porous aquifers formed by the overburdens of hard bedrock aquifers and in hard rock aquifers in concentrations beyond the WHO maximum guideline value of 1.5 mg/L. The occurrence of high fluoride aquifers is often attributed to dry climates as the examples from Argentina, Mexico, Arizona, Israel, India (Bihar, Rajjastan, E India), northern China, Senegal, Kenya, Tanzania and Australia indicate. Further, the mixing of fluoride-rich

geothermal waters into freshwater aquifers can result in high fluoride concentrations in groundwater. Natural sources for fluorine enrichment is evidenced by its occurrence in fumaroles or magmatic gases, hydrothermal deposits, volcanic glasses, the accessory rock minerals of mica and amphiboles, and pegmatitic minerals. The disintegration of these minerals, which is especially due to hydrolysis (combined with a pH increase), may release significant concentrations of fluorine into the soil water and groundwater. The long-term consumption of water with elevated fluoride concentrations affects the health of humans and animals by dental and skeletal fluorosis. Dental fluorosis occurs when drinking water contains fluoride concentrations above 1.5–2.0 mg/L, and skeletal fluorosis occurs when the fluoride concentration exceeds 4–8 mg/L (long-term exposure), depending on the local conditions such as diet, temperature, ingestion of fluorine from other sources.

Our research aims are to better understanding the genesis of high fluoride concentrations in sedimentary aquifers, through investigations of fluoride origin (primary and secondary sources), mobilization from the solid phase, transport and mobility controls. A detailed mineralogical, sedimentological, lithochemical, geochemical, hydrogeochemical and hydrogeological characterisation of the unsaturated and the saturated zone shall therefore be conducted. Leaching experiments (accelerated leaching experiments) using different solutions corresponding to rainwater, soil water, groundwater representative for different hydrogeochemical zones along filtration and flow-paths shall be performed to determine the leachability of fluorine from solid phases to indicate which fluorine sources are the most important ones for dissolved fluorine and to indicate controls for leaching and transport. The role of clay minerals as sites for F-exchange shall be determined.

Key focus of the research is on research of the controls, which determine the fluoride concentration in groundwater, and their individual share to that they contribute: (i) availability of fluorine in rock environments, (ii) mineral equilibria controls by fluorine containing and other minerals such as calcite, fluorite and other F minerals, (iii) the presence of dissolved fluorine complexes and (iii) ion exchange or sorption-desorption processes as probably important controls. Further the propagation of fluoride along groundwater flow paths along from the recharge to the discharge area, considering changes of the mineralogical/geochemical and lithological composition of the aquifer material, groundwater flow velocity (residence time), evaporation, pH, temperature, salinity and hydrochemical composition as function of time are research interests.

Hydrogeochemical modelling shall be used (a) for speciation of the dissolved phases and calculation of saturation states regarding mineral phases, (b) for reaction-path and advective transport calculations involving mineral equilibria and surface-complexation reactions and (c) for inverse geochemical modelling. These calculations shall be carried out along the filtration path-ways of rainwater from the earth's surface to the phreatic water table and for groundwater flowing from the recharge to the discharge area. The results of the leaching experiments shall be correspondingly investigated, and their results reproduced by the calculations. The obtained results of hydrogeochemical and mineralogical changes along pathways shall be used to indicate and to balance fluoride mobility controls.

The results regarding the genesis of the high fluoride concentrations in sedimentary aquifer and the transport and mobility controls, the water supply shall be improved by delimiting zone-types where shallow groundwater with low fluoride concentrations can be expected. This will allow improving the social and economic situation in rural areas, where suitable surface water is absent and shallow groundwater which contains in extended areas high fluoride is often the only economical affordable water resource.

Topic 19: Geology-related Ecotourism for Sustainable Development

Tourism has become one of the world's largest industries. More importantly, ecotourism (defined as "tourism based on scenic and unusual natural features, including wildlife") is the fastest growing sector of the tourism industry. Continued growth is expected, making many developing countries with beautiful natural features, thus far unspoiled by development, increasingly attractive as tourist destinations. When combined with "green" tourism infrastructure facilities such as solar powered transport and hotels with renewable energy powered electricity generation and freshwater production it can attract ecotourists who are spending in average much more than average tourists all in all contributing significantly to social, economic and cultural development if sustainably managed.

Attractions may be rain- and cloud-forests with their rich biodiversity, intermountain desert areas, sandy beaches, coastal morphology, mangrove forests, coral reefs and features more specifically geologic such as active volcanoes, beautiful and dramatic calderas and crater lakes, volcanic manifestations like hot springs, boiling mud pots, and fumaroles. Karst regions, containing caverns on land for exploring and submarine caves for diving, travertine pools and waterfalls, natural bridges, and other scenic features, constitute major areas of actual and potential ecotourism. Other geology related tourism features include coral reefs and glacial landforms. Bathing in thermal waters and mud baths is a natural "stress buster" and the combination of relaxative and curative aspects of thermalism is creating a growing field of thermal health tourism. Geology-related museums, former and presently active mines and geothermal power plants, sites for collecting minerals and fossils, special geologic scenery such as relict glacial topography, are sites of inherent interest to many people, could add to the overall ecotourism industry in countries with such facilities. In sum, there is a wide variety of geologic features and geology-related activities that can be, and should be, exploited to add to the tourism industry in each country.

However, such a development requires the consideration of many aspects through multi- and interdisciplinary research since increasing ecotourism presents the countries with the opportunity to develop a huge potential of socially and environmentally sound tourism but at the same time makes them more vulnerable to environmental impacts. For these reasons ecotourism, conservation, and local community development must be considered as forces reinforcing each other. It is essential to create an extensive system of protected ecological zones and natural features and promote them as tourist areas, conserving them for future generations and contributing to the sustainability of both the protected areas themselves and

the tourism economy. It is essential for each country to recognize both the positive aspects (creation of sustainable employment, increased foreign exchange) and the potential negative effects (degradation of over-used visitor sites or other forms of over-exploitation of ecotourism resources, introduction of new behaviours and diseases) of ecotourism and to protect intensively the national environmental patrimony through legislation.

Ecotourism is a means by which many countries can overcome their socio-economic problems, and simultaneously fulfil their difficult environmental challenges by improving conservation, reducing the presently ongoing deforestation, loss of biodiversity and degradation of the land, which is occurring in varying degrees in many countries. These challenges can be met, or at least the problems moderated, by using the direct and ancillary benefits of natural attractions, including its geological heritage, for promoting and developing ecotourism. The economic and conservation aspects of ecotourism, if well balanced can achieve the multiple optimal benefits of (1) providing social and economic development, both nationally, and, in particular, in rural areas, (2) providing financing for protected areas and conservation efforts, (3) serving as an economic justification for the preservation and management of protected areas, (4) reducing the exploitation of resources from protected and other areas by supplying local people with viable economic alternatives, (5) promoting environmentalism and conservation, and (6) encouraging private conservation efforts.

In many developing and transition countries, there is a large potential for the use of as yet unexploited natural sites for ecotourism. Infrastructure must be improved in order to improve accessibility to, and the facilities at the natural sites be developed for ecotourism. The development of health tourism requires a detailed regional and local analysis of the available geological/geothermal resources. As a second step, site-specific possibilities of each location must be determined, such as the potential of the resources and existing infrastructure. Important requirements for sustainable development will be the social and economic incorporation of local people and communities, the training of qualified personal, increasing investment in financial markets, the modernization of existing tourism centres, ensuring personal security of the visitors, and an increasing awareness of the need to protect the geological resources for their sustainable use, especially through the establishment of laws to regulate the exploitation and protection of the natural sites. The implementation of a well-organized certification program for sustainable tourism programs, such as Green Globe by the World Travel and Tourism Council (WTTC) can provide information to the traveling public about quality ecotourism products and services. Laws for tourist incentives and investments must be designed to favour tourist development by means of fiscal incentives that promote the creation of sustainable tourism products.

Our group has long-term experiences on this inter- and multidisciplinary research area in six Central American countries and is interested to exploit interdisciplinary research in other countries as well.



Irazú volcano that presently is visited annually by over 150,000 tourists (photo: R. Mora)

Topic 20: Climate Change Impact on Groundwater Resources

Global climate change results in changes in terrestrial processes, including the hydrological cycle. It affects surface water volumes, chemistry and quality and in consequence also groundwater recharge (increase or decrease), groundwater storage and consequently groundwater availability and its natural discharge as well as groundwater quality. Increasing seawater levels may also result in an increased invasion of saltwater into coastal freshwater



aquifers. Global climate change also influences biogeochemical reactions and chemical fate and transport in soils, vadose zone and aquifers. Since groundwater becomes on worldwide scale increasingly important for freshwater supply, research on the potential effects of climate change on groundwater systems is an emerging issue. Our research on the complex responses of groundwater to atmospheric conditions associated with climate change is therefore a challenging task.

Topic 21: Uranium in Groundwater and other Geoenvironments

In the industrialized countries especially in the USA, Canada, Australia, and countries of the European Community, uranium (U) was brought recently into focus as a potential drinking-water health hazard. In contrast, in many other countries the U issue is not yet recognized or considered as a potential health problem. This is despite the fact that U concentrations in groundwater are found in many geological settings all around the world. High uranium concentrations, exceeding the provisional WHO limit (15 µg/L) are found groundwater in uranium mineralized areas, hard-rock aquifers (especially granites), sedimentary rocks and unconsolidated sediments. Continuously new regions are detected where the uranium problem was not known so far. Uranium is found in high concentrations in groundwater in oxidizing aquifers ($E_h > 100\text{--}200$ mV) where it is mobile as U(VI) species whereas in reducing aquifers it is immobilized as U(IV) to the solid phase. The western and central part of the USA, many sites in Europe and the 1,000,000 km² covering area of the Chaco-Pampean plain in Argentina are some examples.

Our research attempts to link the occurrence of geogenic uranium in groundwater with providing the human society safe drinking water. Starting from its occurrence in rocks and their mobilization into the groundwater, its distribution and transport in water resources, and uranium removal technologies and other methodologies to mitigate the uranium problem are addressed not only from the technological, but also from economic and social points of view. Such integral viewpoint is required since in the past the selection of inappropriate remediation methods for particular sites have failed, either by not considering hydrogeological or hydrochemical aquifer properties and their temporal variations as well as by ignoring social, cultural and economic conditions of the populations to be served by providing them safe drinking and irrigation water.

This fulfils the sharply increasing worldwide interest in uranium as a potential human health threat which during the last few years has become a hot topic in the society, politics, health organizations/authorities and the drinking water industry as more and more regions are found where the U concentrations in groundwater are exceeding the provisional WHO guideline value of 15 µg/L limit than previously believed.

Topic 22: Water Quality and Livestock Health and Production: Biotransfer of geogenic Toxins from Groundwater to Livestock

Toxic or otherwise harmful geogenic elements contained in groundwater can affect livestock in different ways. Toxins can be directly taken up by the animals through drinking water, or through fodder. In case of the fodder pathway, toxins are mainly associated with the presence of high concentrations of these elements in soils and/or irrigation waters. However, factors such as element speciation, relation of inorganic or organic species, type and composition of soil, and plant species have a major impact on the amount of element uptake, and metabolism by the fodder plant. For the uptake and metabolism of the toxins by livestock, the species of the toxins in fodder is important (e.g. organic or inorganic, type of redox species) since this determines the metabolism of the toxins in the animals, i.e. how much of the toxin is excreted in the urine and how much accumulates in the muscle tissue, in the different organs and in milk. Such elevated concentrations of toxic elements in animal fodder may result in health problems in the animals, reduced production/growth, reduce reproduction, and finally in widespread health risks to consumers, i.e. the humans.

Our research of this area deals to determine the biotransfer processes and their quantification tracing the uptake of geogenic toxins water and soils via feed crops or via drinking water to animals. Biotransfer factors (BTFs), which account for the daily exposure doses of specific toxins to concentrations in animal tissues or its products, quantify biotransfer processes. Biotransfer factors for individual animal tissues, internal organs and for milk, can be determined separately for different uptake routes e.g. from forage or water or from both together. Despite that the transfer of geogenic toxins to animal tissues, inner organs and milk is a complex process, the BTF may be estimated through the water contribution, and the fodder consumption, thereby reinforcing the importance of cattle drinking water quality and forage not only from a productive point of view but also because of its role in exposure to toxins via the human food chain.

Topic 23: Livestock impact on Water Resources and Sustainable Solutions

Large intensive livestock farms are being subject to increasing government regulation. Animal slurries are generally treated by containment in anaerobic lagoons before disposal by spray or trickle application to grassland. Constructed wetlands are sometimes used to facilitate treatment of animal wastes. Some animal slurries are treated by mixing with straw and composted at high temperature to produce bacteriologically sterile and friable manure for soil improvement.

These large volumes of waste manure, which is often used on fields as fertilizer (as it contains high concentrations of nitrogen and phosphorus), can contaminate the local aquifer together with pathogens included in the manure. In addition, livestock operations can impact groundwater resources with antibiotics that are used to promote growth or to treat/prevent bacterial infections and diseases. These antibiotics affect natural bacteria and impact the food

chain, contributing to the rise of antibiotic-resistant bacteria and making it harder to treat human diseases. The seepage of manure nutrients into groundwater largely depends upon the permeability of the soil and the vadose zone and the amount of manure accumulation. The seepage potential is especially high for year-round feedlots where possible leaching of manure nutrients into groundwater is permanent.

Lagoons (i.e. open-air pit filled with urine and manure) also pose significant opportunities for failure since the lagoons can leak or rupture. Sprayfields are another source of groundwater contamination if not applied at rates that crops can absorb. A key problem is that farms produce more manure than their land requires. Nitrates often seep from lagoons and sprayfields into groundwater. If used for dinking this can increase the risk of blue baby syndrome, which may cause not only deaths in infants, but which also has been linked to increases probability of spontaneous abortions. In addition, manure also contains dissolved salts and heavy metals, which may be transported into the groundwater and/or accumulate in the soil or the sediments of the vadose zone and become included in the food chain of animal and humans. It must further be considered that lagoons not only potentially pollute groundwater; but that they also deplete it since many farms use groundwater for cleaning, cooling, providing drinking water, etc.

Tighter regulations and controls on release of contaminants and pathogens into the environment by farms, together with detailed assessment of groundwater vulnerability and a correspondingly adapted design and implementation of pollution-reduction plans, are therefore key topics for research and solutions.

Topic 24: Geothermal Heat for Livestock farming, Fish and Shellfish Cultivation

Several farmed animal species require temperature conditioning within a small range to provide welfare, optimal growth and reproduction. Pig and poultry growing as well as farming of fish and shellfish are important examples. In many areas of Australia and elsewhere this energy for this air conditioning, either by space heating or cooling can be provided in a cheap way from geothermal fluids. These geothermal fluids can be also used to heat/cool the drinking water of livestock to improve welfare and productivity. In case of Australia, geothermal fluids with temperatures between 40 and over 90°C are found in most parts of the Great Basin where water often emerges naturally at artesian wells.

Topic 25: Ecosystem Restoration and Monitoring of Areas Impacted by Mining Activities

Mining of metals and other minerals can results in a significant impact or even the destruction of natural ecosystems through removal of soil and vegetation, influence on surface water bodies, and modifications of unsaturated zone and aquifers, which all can be affected in different way and to different extent. Natural groundwater levels may be decreased; surface and groundwater as well as sediments may become contaminated.

Clean-up of contaminated geoenvironmental compartments such as soils, sediments, aquifers, groundwater, and surface waters is often required. Depending on species of contaminant, contaminant concentration, and extent of contamination, there exists a suite of physical, chemical and biological ex-situ and in-situ options for solutions. Remediation of aquifers, soils, sediments, water, mining deposits, mining effluents and sludges (ex-situ and in-situ) using microbiological processes, ecofriendly biological agents, chemical processes and nanotechnological approaches are our research areas. This also includes design of facilities for safe storage of mine tailings e.g. reactive barriers or treatments for immobilization.

The restoration of mined land requires a suitable planning and monitoring. Adequate planning requires that goals, objectives, and success criteria are clearly established to allow that the reclamation is performed in a systematic way. However, monitoring and an adaptive restoration management, which adapts continuously to the new data and findings obtained during the restoration process, are essential, as the uncertainties in restoration planning can never be overcome.

Topic 26: Coal Seam Gas Exploitation and Underground Coal Gasification: Environmental Impacts and Sustainable Solutions

Underground coal gasification (UCG) converts coal at elevated pressure and temperature in-situ into a gaseous product, called synthesis gas or syngas by the same chemical reactions as they occur in surface gasifiers. As this method coal seams as thin as only 2 m, i.e. otherwise unmineable coal resources, can be exploited so that the coal resource available for using this technique is much larger than those available for classical coal mining methods. In 2000, Australia began a large UCG project in Chinchilla, and presently there are three pilot plant sites for research and development purposes in Queensland that are operated in pilot scale since the regulatory bodies revoked commercial size operation permits due to significant environmental concerns being potential groundwater contamination and surface subsidence the most important ones. Groundwater contamination was for example observed at Hoe Creek, WY, USA, the site of several UCG pilot tests, where improper site selection and over-pressurization of the reactor resulted in contamination of a freshwater aquifer by benzene, volatile organic carbons, and other contaminants. To prevent or minimize these environmental impacts to a sustainable level, an explicit risk management framework, for example a risk-based decision making, can be applied to identify and proactively address the component risks related to UCG siting and operations. This environmental risk assessment requires the consideration of a complex array of changing conditions, including high cavity temperatures, steep thermal gradients, and stress fields obtained during and after the burn process, which can change rock permeability, hydraulic behaviour, geochemical conditions and contaminant transport. In respect to stratigraphy, structure and hydrogeology (hydraulic properties, groundwater flow field, etc.) of potential sites for siting, risk models must be used to evaluate the permeability changes from cavity development and collapse as well as the

effects of changes in buoyancy, thermal and mechanical forces on the transport of inorganic and organic contaminants. Other conditions thereby to consider are the operational variables such as temperature and feed gas composition, which also impact the quantity and species of contaminants produced. A proper restoration of UCG sites is of key importance as well. There is also the possibility of storing CO₂ in the created subsurface space. However, there is significant scientific uncertainty in the environmental risks and fate of CO₂ stored this way. Extensive research comprising geological, geochemical/thermodynamical modelling and laboratory experiments are needed.

The coal seam gas (CSG) industry is a fast growing sector in particular in Queensland. In contrast to UCG where coal is combusted in depth, here the gas (mostly methane) is extracted from the micropores of the coal seams and conducted to the earth's surface. To do so requires that the groundwater level is lowered below the coal seam. This is done by a net of pumping wells resulting in huge amount of CSG coproduced water. The National Water Commission (NWC) of Australia has published the potential for co-produced water in Australia to be 300 GL (10⁶ m³) per year with about 90% of this in Queensland. This is a major national environmental concern in particular since there are inadequate data regarding the extent, the long-term effects from this water production on the surface- and groundwater resources and probable subsidence, the methods of disposal (e.g. reinjection, treatment, use for irrigation, etc.) and related costs,. The NWC is concerned that CSG development represents a substantial risk to sustainable water management given the combination of material uncertainty about water impacts, the significance of potential impacts, and the long time period over which they may emerge and continue to have effect. Effects on community, environment and the economy and industry are unknown making research in these fields crucial and urgent.

Key concerns raised by the NWC that call for urgent research are:

Extracting such large volumes of low-quality water may have impacts on connected surface and groundwater systems (in quantity and quality), some of which may already be fully or overallocated, including the Great Artesian Basin and Murray-Darling Basin.

Impacts on other water users such as agriculture and the environment may occur due to the dramatic depressurisation of the coal seam, including:

- changes in pressures of adjacent aquifers with consequential changes in water availability,
 - reductions in surface water flows in connected systems; drying up of wetlands and springs,
 - land subsidence over large areas, affecting surface water systems, ecosystems, irrigation and grazing lands and possibly damaging buildings, roads and other infrastructure.
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- The production of large volumes of treated wastewater, if released to surface water systems, could alter natural flow patterns and have significant impacts on water quality.
 - The practice of hydraulic or chemical fracking of the coal seams, to increase gas output, has the potential to induce connection and cross-contamination between aquifers, with impacts on groundwater quality of freshwater aquifers.

- The use of CSG water e.g. via irrigation may alter the soil or negatively affect ground-water quality if it reaches the shallow aquifer.
- The treatment of CSG water e.g. through reverse osmosis is producing huge amounts of residual brine whose storage and disposal is an unsolved economic problem.
- The reinjection of treated waste water into other aquifers has the potential to change the beneficial use characteristics of those aquifers.