

Constructed Wetlands for Metals Removal:
Design for Neutral Waters and AMD Remediation

Proposal to the Midwest Hazardous Substance Research Center

Mark Fitch and Joel Burken,
Civil, Architectural and Environmental Engineering
University of Missouri-Rolla

Civil, Architectural and Environmental
Engineering
University of Missouri-Rolla
1870 Miner Circle
Rolla, MO

Phone: 573-341-4431
Fax: 573-341-4729
e-mail: mfitch@umr.edu

Abstract

We propose to extend our research on constructed wetlands for neutral mine drainage towards two primary objectives. The first objective is the development of a model of wetland metal removal suitable for application to design. This model will incorporate the removal mechanisms and kinetics we've determined to be significant in wetlands receiving neutral mine drainage, existing models of sediment Eh due to organic deposition, equilibrium values, and pore water flow models. Measurement of several parameters is required, namely *in-situ* rates of formation of metal sulfides, adsorption rates in pore water, sulfide formation rates from sulfate in the substrate, and rates of coprecipitation with FeOOH. The second objective is to determine removal mechanisms active in acid mine drainage (AMD). Although wetlands for AMD have been widely applied, research on removal has focused almost exclusively on iron removal, either as oxides or sulfides. This focus may overlook adsorption, which could make metals more available than expected and have significant abilities to control shock loads. Therefore adsorption at various pHs will be determined, speciation in AMD wetland sediment will be determined, and pH effect on FeOOH coprecipitation rates will be studied.

For both objectives, field-scale wetlands are our truth. They will be sampled to validate the lab-scale studies and the model. UMR now has access to wetlands at Doe Run (Missouri), Tech Cominco (Trail, BC, Canada), and the Old Bevier Site (AMD, Missouri), and is involved in design of a new wetland for a neutral pH zinc seep in Park City, UT. Such transfer of the technology and knowledge gained from the research remains a priority for this project.

Proposed Period: 8/2004 – 8/2006 (two years)
Proposed Budget: \$143,722 (total over two years)

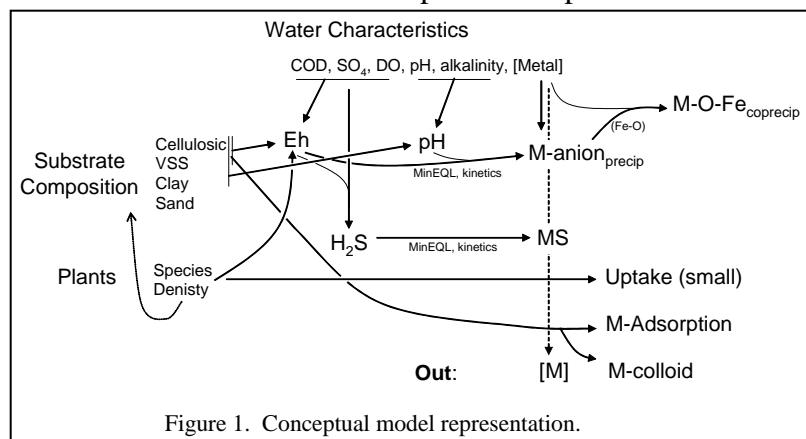
Objectives and Significance

We propose to build on our MHSRC project on constructed wetlands, focusing on design guidance for wetlands treating neutral mine drainage and examining heavy metals removal mechanisms in acid mine drainage. The hypotheses driving this research are:

1. Wetlands receiving metals-contaminated water at neutral pH (6 – 9) may be designed based on a model incorporating kinetics for aqueous equilibrium, adsorption, and biology.
2. Acid mine drainage (AMD) is treated in wetlands by a combination of pH change with resulting precipitative reactions, and similar removal mechanisms to those we've shown in systems receiving neutral mine water.

These broad hypotheses result in a number of objectives relating to the modeling and to AMD removal mechanisms. The model will use known aqueous equilibrium values and measured rate constants as well as water quality characteristics and substrate composition to predict

performance and operation. A conceptual representation of the model is shown in Figure 1. Starting at the inlet to the wetland, the model will iteratively calculate the Eh and pH, amount of chemical precipitation, adsorption on substrate and colloids, generation of new anions (S^{2-} , CO_3^{2-}), and uptake by organisms. Although this



approach seems complex, much of the required information has been independently measured in this and separate research. There are several existing sediment models (ocean floor and riverbed sediment deposition) that predict reductive conditions, which can be adapted to this effort. Similarly, MINEQL+ is widely accepted as predicting equilibrium conditions. Therefore the dominant unknowns relating to model development are hydrodynamics and kinetic rates (for reactions and adsorption). The current state of the science is lacking in these areas. We have measured some rates in our current project and have hydrodynamic tracer tests from past work on failure modes. In the overall development of a mechanistic-based model using applicable rate constants, the following objectives were identified for both lead and zinc:

1. Determine metals adsorption kinetics for wetland substrate and colloidal matter in pore water.
2. Determine kinetics for metal sulfide formation in wetland pore water.
3. Determine kinetics of coprecipitation with iron oxyhydroxides.
4. Investigate metal uptake rates by plants and evaluate significance.
5. Measure sulfide formation rates with differing substrate compositions and ages (using our existing lab-scale wetlands as well as mixing new substrate).
6. Describe the rates at which organic matter is used and is replenished from decaying plant matter.

7. Combine rate constants and equilibrium values with simple hydrodynamic models to create a numerical model of metals removal in wetlands, and validate that model against our lab-scale wetlands.

From the existing, ongoing work we have evaluated a number of these individual mechanisms and have considerable rate constant data. Data for objectives 1 – 3 are already collected, and as previously noted, our current project has included preliminary measurement of these rate constants towards understanding why sulfide removal does not dominate removal mechanisms. Objective 4 reflects our findings that negligible metal uptake is observed in both lab-scale and field-scale plant samples. Objectives 5 and 6 reflect that sulfide formation is most likely limited by carbon cycling (electron donor) rather than sulfate (electron acceptor) in the wetland systems being investigated and that wetland plants are the fundamental source of the electron donor. The final objective ties together the various conceptual removal mechanisms to one research product, a validated model.

The second hypothesis concerns acid mine drainage (AMD). AMD can include many metals; we have chosen to focus on metals that are often reported in AMD, namely Fe, Cu, Mn, Ni, Zn, Cd, and Pb. The majority of the research and implementation to date has focused upon removal of Fe and reduction of total acidity, not upon removal of specific heavy metals (Skousen et al. 1998). AMD wetland systems generally include anoxic lime stone drains to reduce acidity without forming iron oxide armor, followed by oxidizing zones to remove iron and then submerged flow wetlands to trap metals as sulfides and to introduce alkalinity from anaerobic metabolism. Publications on wetland removal mechanisms for heavy metals AMD have been fairly limited in number: Runkel and Kimball (2002) modeled iron oxyhydroxide co-precipitation for free water surface flow; but most studies have focused on metal sulfide formation (Fennessy, 1989; Sobolewski, 1999; Wildeman et al., 1997). The focus on metal sulfides is commendable, because metal sulfides are sparingly soluble and the resulting wetlands are not minimally sized. However, other mechanisms have not been substantially evaluated. Our experience with adsorption as a substantial sink apparently due to faster kinetics indicates smaller wetlands might be designed that remained as effective as those designed based on Machemer's (1993). Selection of wetland media may also be optimized to utilize adsorption properties of selected media, further increasing efficiency. If AMD wetlands involve the same mechanisms as neutral mine drainage, and why should they not, the difference of lower pH can be factored into our existing knowledge to show removal mechanisms and eventually to predict operation. To examine whether AMD removal mechanisms are the same with pH adjustments, the following objectives will be realized:

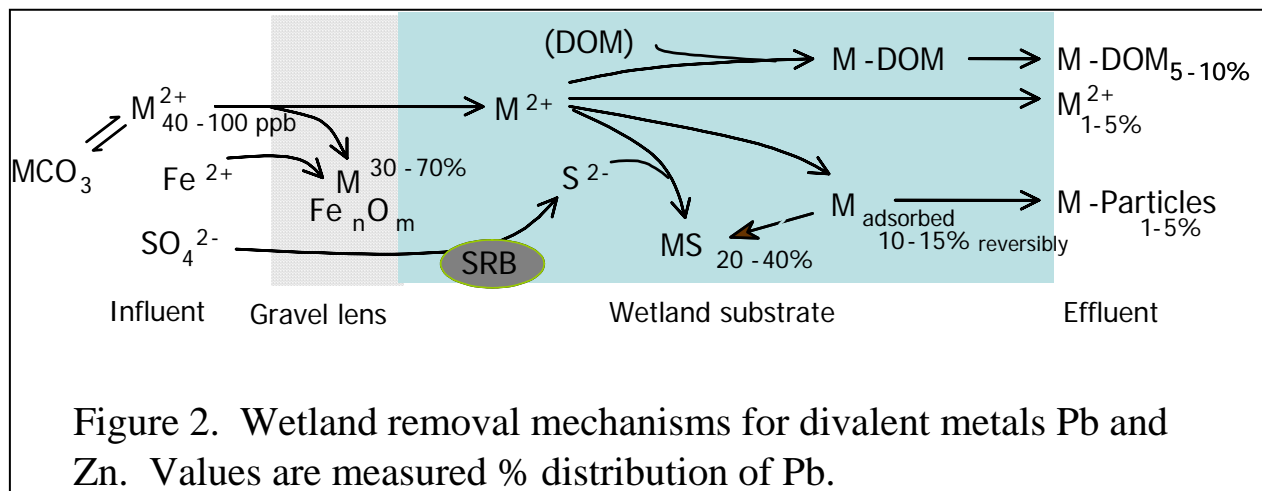
1. Determine adsorption isotherms and kinetics for the metals listed above and substrate between pH 2 and 8, and incorporate these isotherms into adsorption models incorporating pH (Papini et al, 1999).
2. Measure the effect of pH on rates of iron oxyhydroxide co-precipitation.
3. Perform extractive speciation assays, SEM-EDS, and LA-ICP-MS on existing AMD wetlands and compare results with expectations from adsorption, oxidation, and sulfide formation removal mechanisms.

Increased understanding of wetlands for metals treatment leads to design guidelines, and thus to increased acceptance. Although technology transfer is not a separate objective, we will continue such knowledge dissemination. PI Burken is on the ITRC Wetlands team, UMR enjoys a warm relationship with Doe Run, the largest lead and zinc producer in the U.S., and Park City, Utah, is

planning on installation of a wetland to treat zinc mine tailings leachate. Park City contacted UMR because of the MHSRC web site's description of this project. Our UMR group has already assisted Doe Run Mining's chosen engineering firm, Barr Engineering, in design of a constructed wetlands for metals treatment, although construction was cancelled due to a Doe Run personnel change and financial reasons. UMR-Missouri DNR has interacted with the design of the Old Bevier treatment wetlands, which should allow full access to years of AMD wetland data, covering the spectrum of design-failure-redesign and the still sub-optimal treatment occurring at the site. We also intend to expand our tech transfer to international scale; we will contact organizations in less economically privileged countries and determine how we can effectively share our findings. Use of wetlands for developing countries is attractive due to the minimal operational costs and technology in operations (no pumps or chemicals). The wetlands can have a high labor input in construction, and in developing countries, inexpensive labor is often the one resource that is in excess. Through different organizations, such as Engineers Without Borders, design input can be forwarded and implemented on site by local inhabitants or a mission type engineer.

Background Low level release of heavy metals in mine drainage, tailings leachate, and industrial wastewater is a national issue. Constructed wetlands have shown promise for somewhat alkaline mine drainage from lead production, and have been widely used with varying success to treat acid mine drainage (AMD). Initiated by funding from Doe Run, we've operated lab-scale constructed wetlands for six years, with 90% removal of lead and 65% removal of zinc from synthetic lead mine drainage. With feasibility and efficacy proven, we intend to move forward, creating a model for use by design engineers.

The hypotheses arise from this continuing research on wetlands, including three years funded by MHSRC, that determined lead and zinc removal is due to three primary mechanisms, illustrated in Figure 2. Measurement of a field-scale constructed wetland at Tech Cominco in Trail, B.C.,



confirmed our results. We believe the next step is a comprehensive model to predict fate and operation, leading to design based on science rather than anecdote.

AMD is nationally more problematic than the regionally important lead mine drainage we have used, being generally more variable and complex in nature due to the increased solubility of metals and shifts reaction equilibria at low pH. Over the last year a lab-scale AMD wetland was operated and modest removal of metals, 20 – 30% depending on the metal, was observed. The second hypothesis follows from these results: design and operation of wetlands receiving AMD

has frequently been unsuccessful because the design treats all AMD as uniform, neglecting wide disparity in water chemistry. One example of wetland failure is the Old Bevier mine wetland treatment system (described in methods below), for which the initial wetland design worked poorly; indeed the report on the wetland has a section titled “Wetland Failure” (Kim et al, 2003). After failure was clear, the system was redesigned and is still not removing magnesium to sufficient levels. In addition to failure of some AMD wetlands, designs and research have focused on acidity and iron, potentially neglecting more toxic metals in AMD. One very interesting case is arsenic, which is effectively removed in the Tech Cominco wetland despite the strongly reduced conditions.

Significance Failure of constructed wetlands for the treatment of mine drainage must be considered a significant disincentive for the application of these natural treatment systems. In addition to documented failures, design of such wetlands is largely anecdotal. This is unfortunate, because AMD and industrial metal-tainted discharges are substantial problems in the US and worldwide, and constructed wetlands have the potential to successfully and inexpensively treat such discharges. The proposed research is aimed at moving from anecdote to mechanistically-based models. Putting forward knowledge on quantified removal mechanisms and valid design models will advance the acceptance and successful application of these inexpensive treatment systems.

Suitability of Methods

The proposed research is a combination of bench-top batch measurements of rates and equilibrium, lab-scale wetland operation, and measurement of samples collected in the field. The bench-top and lab-scale data will be sources of model parameters, and the model will be validated against lab-scale operation and field-scale observations.

Adsorption assays, used to find rates of adsorption and isotherms, will involve widely-accepted and reported methods. As have been used in our current studies, both batch and flow-through columns will be operated, with time-course aqueous samples filtered and assayed for remaining metal concentration. All experiments include negative and positive controls, and pH is checked and adjusted at the beginning of the assay and after 15 minutes, with a final pH measurement at the end point of the assay. Individual components will be investigated to better understand the contribution of individual components, such as chip bark, peat, hay, and manure. Metals are assayed by flame AA, graphite furnace AA, or ICP-MS, with full calibration and check standards as described in Standard Methods. These adsorption assays are easily applied to different media that are readily available in different regions, such as mushroom compost in the mining regions of Appalachia or the Celgar material (pulping byproduct) used in Trail by Teck Cominco, making the model easily adaptable to optimize for applications in different regions. For example, the Old Bevier rehabilitation used mushroom compost trucked interstate rather than chip bark that is readily available and cheaper in Missouri.

Modeling will include numerical methods and widely-accepted kinetic and equilibrium models (e.g. first-order kinetics and Langmuir adsorption isotherms). Prominent among these will be our use of MINEQL to predict equilibrium concentrations (driving forces for reactions). Simple hydrodynamic models, plug flow with dispersion, will be fitted based on residence time distributions in lab-scale wetlands. The resulting PDEs will be solved with methods involving Matlab or Excel. The seed data for the model is thus measured outside the complex system, and the models will then be tuned using existing and continuing wetland results at both lab and field

scale. Sensitivity analysis will show the parameters with greatest uncertainty on the operational results.

Once the steady-state modeling is successful, the model will be expanded to include temporal changes. Time steps will allow for variation in influent composition, biological activity (seasonal), and sediment decomposition and renewal. Our six-year record of data will be used to validate and calibrate this larger model. The models will let us better understand why wetlands are effective at metals removal and will allow us to begin to design wetlands better than the current combination of first-order kinetics and hard-learned advice about plant species, sediment composition, and flow configuration.

Metal sulfide formation rates will be determined in *in-situ* batch assays using dialysis samplers and by simple batch chemical addition. The latter is the simple mixture of solutions of metal salt and sodium sulfide, buffered to simulate pore water, with measurement of time-course aqueous metal concentrations from samples withdrawn through filters. These assays will give rates of metal sulfide formation in idealized conditions, but the rate of sulfide evolution may be limiting rather than the rate of the reaction. Thus *in-situ* measurement is desired. To remove adsorption as a competitive mechanism, diffusion samplers (Wright & Otte, 1999) will be placed in wetlands. Mass transfer resistance of the diffusion samplers will be determined *ex-situ* by introducing fresh deionized water into diffusion samplers in sulfide solutions and time-course sampling for sulfide transferring into the samplers. The *in-situ* samplers will have Pb introduced and will be similarly sampled, showing the rate of PbS formation. The diffusion membranes have a low enough molecular weight cut off to retain lead, and samplers will be end-point sampled to determine the mass closure and mass of lead sulfides formed.

Fe-O coprecipitation will be assayed in batch experiments involving the admixture of metal salt solutions and oxygen-saturated water in sealed containers. Desired dissolved oxygen (DO) concentrations will be maintained by means of a control system delivering air and using a signal from a DO probe. pH is verified as described for adsorption experiments. Time-course samples are withdrawn, immediately filtered, and acidified, with the final sampling using the entire solution. The retentate on the filter will be acidified to dissolve and measured to verify mass balance closure.

Sulfide formation rates will be found in small lab-scale wetlands receiving groundwater amended with sulfate to 500 mg/L. Various mixtures of substrates will be used, with a consistent manure, sludge, sand, and gravel content but varying the organic source amongst chip bark, peat moss, and spent mushroom compost. Sulfate reduction will be determined, with the assumption that all sulfate removal is biological. Existing pC-pH relationships will be used to calculate the relative concentrations of H_2S , HS^- , and S^{2-} that result.

Plant uptake rates are expected to be minimal. We have measured metal content of plants in our wetlands, Tech Cominco's treatment wetland, and natural wetland areas receiving mine drainage, with consistently low measured concentrations. Uptake will be measured by determining plant growth and ending metal content during one year in sediment and hydroponic channels in lab-scale wetlands. The plant species examined in the lab will be cattails (*Typha latifolia*), bulrush (*Scirpus validus*) and duck potato (*Sagittaria latifolia*). As Old Bevier mine has surface flow cells, any macrophytes such as duckweed (*Lemnaceae* spp.) that colonize the wetlands will also be tested for metals content. All plant samples tested will be surface washed prior to analysis, as surface deposition can be mistaken for uptake. Overall bioaccumulation of heavy metals in a

freshwater wetland is not considered to be problematic, rather Pb and As were shown to bioaccumulate (Chen and Folt, 2000)

Field samples will be collected from various sites. At the Tech Cominco treatment wetland we have already sampled for plant uptake of metal and surface sediments. Last year we installed sampling “socks” of media in perforated tubes driven deep into the wetland; these socks will be analyzed for metal speciation over time, with the first set of socks to be pulled this June. In addition to Tech Cominco’s wetland, we will continue to sample nature wetlands on Doe Run property, and will explore sampling of the wetland at one Doe Run mine site. The Park City, Utah wetland, assuming it is constructed as planned (PI Fitch will be there in June to help build the pilot-scale unit), will also be sampled. New sites for this study will focus on acid mine drainage. The PIs enjoy a good relationship with Missouri’s DNR, including past work with the Old Bevier mine’s wetland planned as one sampling site. Old Bevier mine was an active underground and strip coal mine from 1859 until the late 1950’s, near Moberly MO. The closed mine has numerous seeps collected by drains, with pH in the 2-3 range, 700 mg/l as CaCO₃ total acidity and an Fe content of 450 mg/l. A surface flow constructed wetland was installed in the 80s, with an average flow rate of 45 gallons per minute. The 5-cell wetland was ineffective in maintaining a pH in the effluent above 3, although the total acidity was reduced to 100 – 200 mg/l. Cells 4-5 were totally void of vegetation and heavily armored with iron oxyhydroxides after 3 years. The PIs sampled the wetland at this time, profiling Fe, pH and total acidity through the multi cell system. Following investigation, the failed system was redesigned in 2001 (without design input from the PIs) to include a vertical flow subsurface wetland, similar in design to those at UMR, to treat the acidity and extremely high Fe. The current system performs up to expectations with respect to acidity and Fe, but is not removing Mg as anticipated (Kim et al, 2002). In review of the design documents, the design was solely based upon Fe removal and did not consider Mg individually, stating that Fe was in such excess design is based upon Fe alone. No design consideration of other metals is essentially consistent in the design documents for AMD wetlands (Kleinmann and Hedin, 1993; Hedin et al. 1994; Skousen et al, 1998).

Metals forms in sediment. We have successfully applied Tessier’s (1979) method to measure metal extractability. A significant volume of literature has confirmed that extractive speciation methods suffer from inaccuracies but broadly reflect metal chemistry (Nirel and Morel, 1990; Raksataya et al., 1996). These methods will continue to be used in this work. However, UMR is currently acquiring a laser ablation ICP-MS. The use of Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) provides analysis of multi-element solution samples at parts-per-billion to part-per-trillion concentration levels, utilizing extremely small sample sizes. The associated laser ablation sampling system (LA-ICP-MS) allows for solid phase sampling of sediment material directly. The laser system can be focused down to beam diameters in the 10’s of micrometers, with minimal interference from surrounding regions. Pulsed laser systems can be used for depth profiling. Although sediments/wetland material may be dissolved and analyzed by conventional ICP-MS techniques, the process of solid phase analysis by LA-ICP-MS is more desirable because it allows investigators to examine fine-scale compositional differences (e.g., composition zoning), and avoids problems in analyzing phases that are resistant to acid digestion processes (Gunther, 2001; Veinott, 2001).

Sampling will include existing laboratory wetland media that has sequestered Pb and Zn for 6 years, and the AMD wetland now operating for more than one year. We are studying a median AMD composition in current research. Media will be removed from the wetlands to profile the spatial variability, sampling from three depths at the front, middle and end of the wetland.

Media samples will be filter dried and directly sampled via LA-ICP-MS. Media sampling via LA-ICP-MS will allow for multiple metal analyses of samples, as well as other elemental constituents. Sampling with LA will also provide scanning capability, to look at the spatial deposition of the targeted metals. Solid sampling should provide compositional determination as metals sulfides or iron oxyhydroxides, by concurrent determination of Fe and S. Determining such composition is not feasible via other analytical techniques, in particular for the microscale solid sampling feasible with laser ablation. The concurrent determination of Fe and S will indicate the composition of the sequestered metals. Model calibration will be conducted using the results of the wetland sampling. Similar sampling will also be conducted on the existing wetlands, 2 years old, that are receiving NMD and AMD side by side. Concurrent to all solid phase media sampling, aqueous sampling of the pore water will be carried out. This will establish aqueous-precipitate concentration relationships for comparison to the batch and MINEQL modeling efforts. LA methods should be noted as 'semi-quantitative' as calibration to determine absolute concentrations is difficult. The ablation process vaporizes slightly different volumes given the media adsorption properties. As the standards will be comprised of different materials, the calibration is not used as an absolute. Therefore, acid digestion and total metals concentrations will be determined via liquid ICP-MS for a sub-sample, roughly 0.5 g, of each wetland media sample. Combined sampling will provide a quantifiable total metals concentration and a detailed speciation that is semi-quantitative.

Qualifications

The PIs have a 6-year record of funded research on constructed wetlands treating metals in neutral mine drainage, and PI Burken is internationally recognized in the area of phytoremediation. This continuing work has resulted in several publications and submissions (Fitch, 2000; Song et al., 2001; Leersen et al, 2004; Ye et al, 2004; Fitch et al, 2004), and also in industrial interest such as the design of a full scale wetland designed for Doe Run's Buick facility. Construction on this system was tabled for reasons including cost estimates of approximately \$1 million. Doe Run remains nonetheless interested in application of the technology to mine sites and tailings leachates. Park City, Utah has recently contacted us for

Partners and Resources: A variety of partners are on board with this project: Doe Run continues to support us by allowing site access for field samples and personnel time. Tech Cominco has allowed us to sample from their treatment wetland in Trail BC, shared data from that system, and devoted personnel and subcontractor time to this project. We estimate continued assistance at a rate similar to the current, \$5,500 each year in personnel time and access to the site and data from the site. Barr Engineering designed the Doe Run wetland, and has agreed to interact on design guideline development. Park City, UT has committed \$50,000 to install a full-scale system, with UMR involved in the pilot-scale unit and assisting in the full project; this is not seen as matching funds and so not noted in the budget. Matching from these sources is anticipated in the form of personnel time, travel funds and site access, and UMR will match with salaries of faculty and staff for an expected total of approximately \$35,000 each year.

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Itemized Budget for Constructed Wetlands for Metals Removal

CATEGORIES	YEAR ONE	YEAR TWO	TOTAL PROJECT
A. Personnel			
PI Mark Fitch	\$ 4,000.00	\$ 4,200.00	\$ 8,200.00
Co-PI Joel Burken	4,000.00	4,200.00	8,200.00
Graduate Students	19,998.00	20,197.98	40,195.98
Technician	901.50	901.50	1,803.00
Undegraduate Students	6,000.00	6,000.00	12,000.00
TOTAL PERSONNEL COSTS	34,899.50	35,499.48	70,398.98
B. Fringe Benefits			
25 % of PI, Co-PI & Technician	2,428.33	3,100.19	5,528.52
C. Travel			
HSRC Conference	600.00	600.00	1,200.00
Present at National Conference		1,500.00	1,500.00
Site Visits	2,500.00	2,500.00	5,000.00
TOTAL TRAVEL COSTS	3,100.00	4,600.00	7,700.00
D. Equipment			
TOTAL EQUIPMENT COSTS	-	-	-
E. Supplies			
Chemicals, glassware	1,400.00	1,400.00	2,800.00
Publication	300.00	300.00	600.00
Office	50.00	50.00	100.00
GFAA	200.00	200.00	400.00
TOTAL SUPPLY COSTS	1,950.00	1,950.00	3,900.00
F. Contracts			
TOTAL CONTRACTUAL COSTS	-	-	-
G. Other			
Educational Fees/Tuition	6,366.36	6,939.33	13,305.69
TOTAL OTHER COSTS	6,366.36	6,939.33	13,305.69
H. TOTAL DIRECT COSTS (sum of A-G)	\$ 48,744.19	\$ 52,089.00	\$ 100,833.19
I. INDIRECT COSTS 49% of H less educational fees	20,765.14	22,123.34	42,888.47
J. TOTAL PROJECT COSTS (sum of H & I)	69,509.33	74,212.34	143,721.67
K. TOTAL REQUESTED FROM EPA	\$ 69,509.33	\$ 74,212.34	\$ 143,721.67

**Year 1 Budget
(8/2004 – 8/2005)**

Category	EPA	UMR	Doe Run	Tech Cominco
A. Personnel				
1 Mark Fitch, Asst. Prof., mo =	0.5 \$ 4,000.00	0.05 AY \$ 3,600.00		
2 Joel Burken, Asst. Prof., mo=	0.5 4,000.00	0.05 AY 3,600.00		
3 Chang Ye, PhD student	19,998.00			
4 Technician	901.50	Department match 1,803.00		
5 Undergraduate Students, hrs =	800 6,000.00			
			Personnel time, sampling \$ 750.00	\$ 2,500.00
B. Fringe benefits				
27.28% of A1, A2, and A4	2,428.33	2,250.75		
Salary & Wages Subtotal	37,327.83	11,253.75	750.00	2,500.00
C. Equipment				
D. Travel				
1 To present at HSRC	600.00			
2 Travel to sites	2,500.00	Travel for UMR personnel		
E. Supplies				
1 Chemicals, glassware	1,400.00			
2 Publication	300.00			
3 Office	50.00			
4 GFAA	200.00	6,000.00	3,000.00	3,000.00
F. Educational fees				
	6,366.36			
Costs				
Total Direct	\$ 48,744.19	\$ 17,253.75	\$ 3,750.00	\$ 5,500.00
Modified Total Direct	\$ 42,377.83	\$ 17,253.75	\$ 3,750.00	\$ 5,500.00
Indirect, on MTDC at a % rate of	49 \$ 20,765.14	Indirect, 49% rate \$ 8,454.34	-	-
		Indirect waiver		
Total	\$ 69,509.33	\$ 25,708.09	\$ 3,750.00	\$ 5,500.00
		Match Sum: \$ 34,958.09		

**Year 2 Budget
(8/2005 – 8/2006)**

Category	EPA	UMR	Doe Run	Cominco
A. Personnel				
1 Mark Fitch, Asst. Prof., mo =	0.5 \$ 4,200.00	0.05 AY \$ 3,600.00		
2 Joel Burken, Asst. Prof., mo=	0.5 4,200.00	0.05 AY 3,600.00		
3 PhD student	20,197.98			
4 Technician	901.50	Department match 1,803.00		
5 Undergraduate Students, hrs =	800 6,000.00			
		Personnel time, sampling	\$ 750.00	\$ 1,200.00
B. Fringe benefits				
33.3% of A1, A2, and A4; 1.1% of A3	3,100.19	2,250.75		
Salary & Wages Subtotal	38,599.67	11,253.75	750.00	1,200.00
C. Equipment				
D. Travel				
1 To present at HSRC	600.00			
2 To present at Nat'l conf.	1,500.00			
3 Travel to sites	2,500.00	Travel for UMR personnel		1,200.00
E. Supplies				
1 Chemicals, glassware	1,400.00			
2 Publication	300.00			
3 Office	50.00			
4 GFAA	200.00	6,000.00	3,000.00	3,000.00
F Educational fees				
	6,939.33			
Costs				
Total Direct	\$ 52,089.00	\$ 17,253.75	\$ 3,750.00	\$ 5,400.00
Modified Total Direct	\$ 45,149.67	\$ 17,253.75	\$ 3,750.00	\$ 5,400.00
Indirect, on MTDC at a % rate of	49 \$ 22,123.34	Indirect, 49% rate \$ 8,454.34	-	-
Total	\$ 74,212.34	\$ 25,708.09	\$ 3,750.00	\$ 5,400.00
		Match Sum: \$ 34,858.09		

Mark W. Fitch, Ph.D., E.I.T.

Associate Professor of Civil Engineering
University of Missouri-Rolla, Rolla, MO 65409
(573) 341-4431 Fax: (573) 341-4729
e-mail: mfitch@umr.edu

Education:

Doctor of Philosophy in Chemical Engineering (3/96), The University of Texas at Austin.

Used microbiological and engineering techniques to optimize trichloroethylene degradation by *Methylosinus trichosporium* OB3b in a hollow fiber membrane reactor.

B.S. with Honors in Chemical Engineering (12/89), The University of Texas at Austin.

Emphasis on polymers; Undergraduate research in polymer permeability.

Professional Experience:

Consultant, Barr Engineering/Doe Run, Minneapolis, MN

Design of constructed wetland to reduce toxicity of metal smelter wastewater.

Consultant, Winthrop & Weinstine P.A., Minneapolis, MN (5/00)

Analysis of radionuclide source and magnitude at a site.

Senior Environmental Engineer T.I., Burns & McDonnell, St. Louis, MO (5/98 – 8/98)

Design and review of industrial wastewater treatment facilities, municipal wastewater facilities, and lift stations. Continuing in a consulting capacity, 10 – 100 hours per year.

Consultant, Baxter Healthcare, Chicago, IL (5/89-7/89)

Characterization of CO₂ permeation through novel polyolefin films.

Academic Experience:

Associate Professor, University of Missouri-Rolla (9/02 – present)

Visiting Associate Professor, University of Illinois Urbana Champaign (9/03 – present)

Assistant Professor, University of Missouri-Rolla (3/96 – 8/02)

Research focus on bioremediation. Pursuits include: metals and radionuclide transport in soils and sediments, intrinsic cometabolism of chlorinated solvents by methanotrophs; intrinsic and bioaugmented remediation of petroleum hydrocarbons; degradation of volatile organic compounds from air streams using membrane bioreactors; and constructed wetlands studies for metals removal.

Student Supervision:

Current: 2 Ph.D., 4 M.S. (Thesis), 2 Undergraduate

Past: 1 Ph.D., 6 M.S. (Thesis), 1 M.S. (ABT), 8 M.S. (Non-thesis), 26 Undergraduate

Honors:

Awards: Jefferson Smurfit Faculty Exchange (University College Dublin, Ireland), 2002
Oak Ridge Associated Universities Junior Faculty Enhancement Award, 1997

Societies: Tau Beta Pi, 1988; Omega Chi Epsilon, 1989

Grants:

P.I. or co-P.I. on \$785,000 in past and current grants (Fitch only, total \$2,907,000 for all PI's & co-P.I.s).

Selected Publications:

Song, Y., Fitch, M., and J. Burken, (2003) "Sulfide Generation and Metal Removal by Sulfide Precipitation in Constructed Wetlands", submitted to, April 2003.

Fitch, M.W., Neemann, J., and E. England, (2003) "Mass Transfer and Benzene Removal from Air Using a Latex Rubber and Hollow Fiber Membrane Module", Appl. Biochem. Biotechnol. 104: 199-214.

Fitch, M.W., England, E., and B. Zhang, (2002) "n-Butanol Removal from a Contaminated Air Stream Under Continuous and Diurnal Loading Conditions", J. Air Waste Man. Assoc. 52: 174-183.

- Fitch, M.W., and E. England (2002) "Radionuclide Leaching from Residual Soils: A Screening Study", ASCE Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management, 6 (3), 184-189.
- Song, Y., Fitch, M., Burken, J., Nass, L., Chilukuri, S., Gale, N., and C. Ross, (2001) "Lead and Zinc Removal by Lab-Scale Constructed Wetlands", Water Environ. Res., 73 (1), 37-44.
- Fitch, M.W., Lam, A.C., and R.L. Segar, (2000) "Biological Treatment Systems", Water Environ. Res., 72 (5).
- Ergas, S.J., L. Shumway, M.W. Fitch, J., and J. Neemann, (1999) "Membrane Process for Biological Treatment of Contaminated Gas Streams," Biotechnology and Bioengineering, 63 (4), 431-441.
- Fitch, M.W., D. Weissman, G. Georgiou, P. Phelps, and G.E. Speitel Jr., (1996) "Trichloroethylene Degradation by Methylosinus trichosporium OB3b Mutants in a Sequencing Biofilm Reactor," Water Research, 30(11): 2644-2655.
- Fitch, M.W., G.E. Speitel Jr., and G. Georgiou, (1996) "Trichloroethylene Degradation by Methanol Grown Cultures of Methylosinus trichosporium OB3b PP358," Appl. Environ. Microbiol., 62(3): 1124-1128.
- Aziz, C.E., M.W. Fitch, L.K. Linquist, J.G. Pressman, G. Georgiou, and G.E. Speitel Jr., (1995) "Methanotrophic Biodegradation of Trichloroethylene in a Hollow Fiber Membrane Bioreactor," Environ. Sci. Technol., 29(10): 2574-2583.
- Fitch, M.W., D.W. Graham, R.G. Arnold, S.K. Agarwal, P. Phelps, G.E. Speitel Jr., and G. Georgiou, (1993) "Phenotypic Characterization of Copper-Resistant Mutants of Methylosinus trichosporium OB3b," Appl. Environ. Microbiol., 59: 2771-2776.
- Fitch, M.W., W. Koros, R. Nolen, and J. Carnes, (1993) "Permeation of Several Gases through Elastomers, with Emphasis on the Deuterium/Hydrogen Pair," *J. Appl. Polymer Sci.*, 47: 1033-1046.

Selected Conference Papers & Presentations:

- Fitch, M., (2003), "Offering Teaching Engineering", presented to the Thirteenth Annual Teaching Renewal Conference, Columbia, MO, 1 March 2003.
- England, E., and M. Fitch, (2002), "Heat Transfer and Toluene Removal in Bench-Scale Membrane Reactors", Paper #42969 in Proceedings of the Air & Waste Management Association's 95th Annual Conference & Exhibition, June 23-27, 2002 (Baltimore, MD, 2002).
- Fitch, M.W., Mihalcik, P.K., and O.V. Singh, (2002), "Fate of Transgenes: DNA Extraction from Soils", presented to the University of Missouri and Monsanto Protein Technologies Research Symposium on Plant-Made Pharmaceuticals, Columbia, MO, 22 October 2002.
- Gilbertson, A.W., Burken, J.G., and M.W. Fitch, (2002), "Fluorescent, Root-Colonizing Recombinant Bacteria to Enhance the Rhizosphere Degradation of TCE", In Situ and On-Site Bioremediation: Papers from the Fourth International In Situ and On-Site Bioremediation Symposium (Monterrey, CA, 2002), Battelle Press., paper 2B-25
- Gilbertson, A.W., Burken, J.G., and M.W. Fitch, (2001), "Recombinant *gfp*-tagged Root-Colonizing Microbes: Implications on Phytoremediation", in Phytoremediation, Wetlands, and Sediments, Proceedings from the 6th International In Situ and On-Site Bioremediation Symposium, Leeson, A., Foote, A.A., Banks, M.K., and V.S. Magar, Eds., pp. 199 – 205.
- Fitch, M.W., Sauer, S., and B. Zhang, "Membrane Biofilters: Material Choices and Diurnal Loading" 2000 USC-TRG Conference on Biofiltration (Los Angeles, CA, October 19 – 20, 2000), The Reynolds Group, 83-90.

Technical Reports and Other Non-refereed Publications:

- Fitch, M.W., and Burken, J.G., "Midwest Hazardous Substance Research Center Brief #1: Constructed Wetlands for Metals Removal", Midwest Hazardous Substance Research Center, Purdue, July 2003, 3 pp.
- Fitch, M.W., "Leaching of Radionuclides from St. Louis Airport Site Soils", United States Geological Survey and United States Environmental Protection Agency, April 15, 1999, 101pp.
- Fitch, M.W., and Wronkiewicz, D., "K_d of Radionuclides and Chlorinated Solvents in Soils from the Combustion Engineering Site", Leggette, Brashears & Graham, February 19, 1999, 50 pp.
- Fitch, M.W., and Burken, J.G., "Metals Removal by Constructed Wetlands: Final Report to The Doe Run Company", The Doe Run Company, May 26, 1998, 12 pp.
- Fitch, M.W., and Neemann, J., "Phosphate Removal for Tracker Marine", Final Report, University of Missouri-Rolla, Rolla, MO, March 1997, 12 pp.

Joel Gerard Burken, Ph.D., E.I.T.

EDUCATION

- Ph.D. in Civil & Environmental Engineering, University of Iowa, Iowa City, Iowa, Dec., 1996. Dissertation: Fate and Uptake of Organic Contaminants by Hybrid Poplar Trees.
- M.S. in Civil & Environmental Engineering, University of Iowa, Iowa City, Iowa, Aug., 1993. Thesis: Vegetative Uptake by Populus sp. and Mineralization of Atrazine in Variable Soil Types.
- B.S. with Honors in Civil & Environmental Engineering, University of Iowa, Iowa City, Iowa, Dec., 1991. Honors Paper: Simulation of Steering Dynamics.

PROFESSIONAL EXPERIENCE

- 2002- Present Associate Professor, Coordinator Environmental Engineering Undergraduate Program, University of Missouri-Rolla, Department of Civil, Architectural, and Environmental Engineering. Research Investigator Environmental Research Center.
- 1997- 2002 Assistant Professor, University of Missouri-Rolla, Department of Civil Engineering. Research Investigator Environmental Research Center.
- 1995 Swiss Federal Institute for Environmental Science and Technology (EAWAG), Research Intern.

HONORS AND AWARDS

National

- Best Student Paper Award: Fourth International Conference on Remediation of Chlorinated and Recalcitrant Compounds; Battelle International; authors - G. C. Struckhoff, J.G. Burken, J. G. Schumacher
- Faculty Early Career Development (CAREER) Award 2000, National Science Foundation.
- Who's Who Among America Teachers 2002
- Who's Who in America 2001, 55th Edition.
- 1998 Rudolph Hering Medal for the Most Valuable Contribution to the Environmental Branch of Engineering, American Society of Civil Engineers, for the paper "Phytoremediation: Plant Uptake of Atrazine and Role of Root Exudates."

Regional/Local

- Joseph Senne Award – 2003 "Most Outstanding Professor in Civil, Architectural & Environmental Engineering" – UMR Academy of Civil Engineers
- 3 - University of Missouri-Rolla Faculty Excellence Awards, 1999-2000, 2000-2001, 2002-2003.
- Nominated by UMR for the 2001 ASEE Midwest Section Outstanding Teaching Award.
- Nominated for the 2002 James Robbins Outstanding Teaching Award from Chi Epsilon

PUBLICATIONS (PEER REVIEWED (SELECTED OF 25))

BOOK CHAPTERS/REPORTS

- Burken, J.G. (2003) "Uptake and Metabolism of Organic Compounds: Green-Liver Model" In: Phytoremediation: Degradation and Control of Contaminants, eds S.C. McCutcheon and J.L. Schnoor, John Wiley and Sons Publishers, New York. pp 59-84.
- Burken, J.G., J.V. Shanks, and P.L. Thompson. (2000) "Phytoremediation of Explosives and Nitroaromatic Compounds" In: Biodegradation of Nitroaromatic Compounds, eds. J.C. Spain, J.B. Hughes, J.N. Knackmuss, Lewis Pubs, Boca Raton FL, p. 239 – 276.
- Schumacher, J.G. Struckhoff, G.C. Burken, J.G. (2004) Assessment of Subsurface Chlorinated Solvent Contamination Using Tree Cores at the Front Street Site and Former Dry Cleaning Facility at the Riverfront Superfund Site, New Haven Missouri, 1999-2003. U.S. Geological Survey Scientific Investigations Report 2004-5049, 35pp

JOURNAL ARTICLES

- Ma, X. and J.G. Burken (2003) **TCE Diffusion to the Atmosphere in Phytoremediation Applications.** *Environmental Science and Technology* **37** (11) 2534-2539:
- Ma, X. and J.G. Burken (2002) **VOCs Fate and Partitioning in Vegetation: Use of Tree Cores in Groundwater Analysis.** *Environmental Science and Technology*, **36** (21) 4663 – 4668.
- Raschke, H., M. Meier, J.G. Burken, R. Hany, M.D. Müller, J.R. van der Meer, and H.P. Kohler (2001) **Biotransformation of Various Substituted Aromatic Compounds to Chiral Dihydrodihydroxy Derivatives.** *Applied and Environmental Microbiology* **67** (8) 3333 – 3339.
- Shim, H., S. Chauhan, D. Ryoo, K. Bowers, S. M. Thomas, K. A. Canada, J. G. Burken, and T. K. Wood. (2000). **Rhizosphere Competitiveness of Trichloroethylene-Degrading, Poplar-Colonizing Recombinants.** *Applied and Environmental Microbiology*. **66**: 4673 – 4678.
- Burken, J.G. and J.L. Schnoor (1998). **Predictive Relationships for the Uptake of Organic Contaminants by Hybrid Poplar Trees.** *Environmental Science and Technology*, **32**(21): 3379 – 3385.
- Burken, J.G. and J.L. Schnoor (1997). **Degradation of Atrazine and Metabolites by Poplar Trees.** *Environmental Science and Technology*, **31**(5): 1399 – 1406.
- Burken, J.G. and J.L. Schnoor (1996). **Phytoremediation: Plant Uptake of Atrazine and Role of Root Exudates.** *ASCE Journal of Environmental Engineering*, **122**(11): 958 – 963.

INVITED SPEAKER

- “Phytoremediation of Chlorinated Organics” National Environmental Research Institute (NERI) Roskilde Denmark, August 12, 2003
- “Rhizosphere Degradation of Chlorinated Solvents using GFP-Tagged Microorganisms.” American Society of Microbiology, Washington D.C. May 18 – 22, 2003
- “Removal and Fate of Chlorinated Solvents from Contaminated Groundwater” U.S. EPA International Applied Phytotechnologies Conference, Chicago, IL. March 3 – 5, 2003
- “Phytoremediation Applications” Pan American Advanced Study Institute (NSF-sponsored workshop), Rio de Janeiro, Brazil, July 22-August 3, 2002.
- “Chasing Subsurface Contaminants”, Phytoremediation: State of the Science Conference, U.S. EPA , Boston, MA, May 1-2, 2000.
- “Phytoremediation of Explosives and Nitroaromatic Compounds”, Second International Symposium on Biodegradation of Nitroaromatic Compounds and Explosives, U.S.A.F. Office of Scientific Research, Leesburg, VA, September 8-9, 1999.
- “Uptake and Potential Volatilization of Common Organic Contaminants by Hybrid Poplar Trees”, 7th Annual INTERCOL Conference: Phytoremediation Workshop, Florence, Italy. July 19-25, 1998.

SERVICE

- Established Environmental Engineering Degree Program, Currently Coordinator, UMR, 20002
- President, ASCE Mid. Missouri Section 2000-2001 (Vice Pres. 1998 – 2000).
- Associate Editor: *International Journal of Phytoremediation*
- Editorial Board Member, *Bioremediation and Bioavailability* domain, *TheScientificWorld Journal*
- Guest Editor: *International Journal of Phytoremediation*, 1999; *ASCE Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management*, 2001.
- Associate Editor, *AEESP Environmental Engineering Processes Laboratory Manual* (2000 – 2001).
- Member: Interstate Technology Regulatory Council (ITRC) Committee for Constructed Wetlands; Remedial Technologies Development Forum (RTDF) Phytoremediation of Organics Action Team.
- Committees: Chairman AEESP National Committee on Student Organizations, AEESP Publications Committee, Technical Committee for 2000 ASCE National Environmental Engineering Division Conference, ASCE Zone III Nominating Committee (1999, 2000).