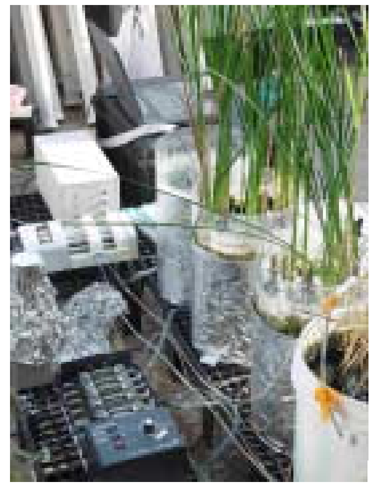
Experimental and mathematical Simulation of the Dynamics of Trace Metals in Wetland Sediments

Plants are ubiquitous in wetland environments and play important roles in many biogeochemical processes that are involved in the degradation and transformation of a wide variety of pollutants. Wetland plants can transport a significant amount of oxygen from the atmosphere into the rhizosphere and this oxygen can affect reactions that may control the behavior of many pollutants (such as chromium and arsenic). Organic exudates from plant roots, root turnover, and plant litter, all serve as a reducing force in the sediments and thus drive many reduction processes. Wetland plants also transpire large quantities of water from the sediments to the atmosphere and this process often induces vertical transport of dissolved species.



To investigate the effects of wetland plants on the behavior of important redox species (such as iron) and pollutants (such as chromium), continuous flow wetland microcosms have been built and operated in a greenhouse (see the picture above). Cattail and phragmites, both common wetland plants, were grown in these microcosms. Nutrient solutions amended with carbon sources and heavy metals were pumped through the microcosms, and the vertical profiles of different chemical constituents were monitored over time. The diurnal dynamics of iron (an important redox species that may adsorb anions such as chromate when precipitated as ferric hydroxide and release pollutants once reduced and dissolved) in the rhizosphere was tracked using a gold-amalgam microelectrode. Results show a clear diurnal pattern in iron(III) concentrations, which we attribute to the plant transpiration (strong during the daytime, so iron(III) is concentrated) and plant oxygen release into the sediments (also strong during the day time, so reduction of iron (III) is inhibited and/or iron(II) may be oxidized).

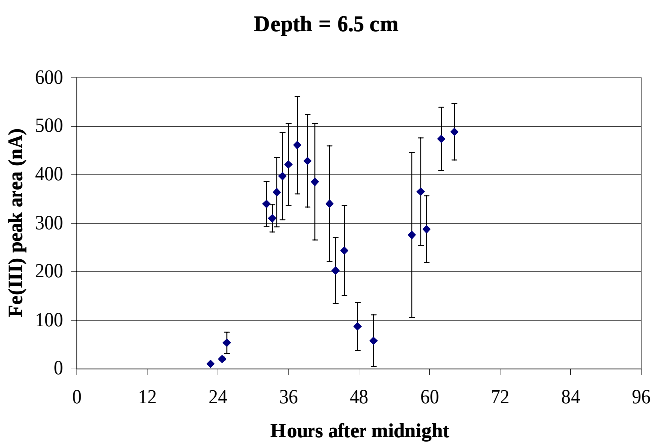


Figure 2. Diurnal variations in Fe(III) in the planted microcosms

Vertical concentration profiles of sulfate (Fig. 3), illustrate the effects of plant evapotranspiration. Compared to the water discharge rate, which was set at about 300 ml/day for each microcosm, the intensity of transpiration is so strong that sulfate concentration more than doubled at the bottom of the microcosms. For systems where the discharge rate is lower, this effect will be even more significant.

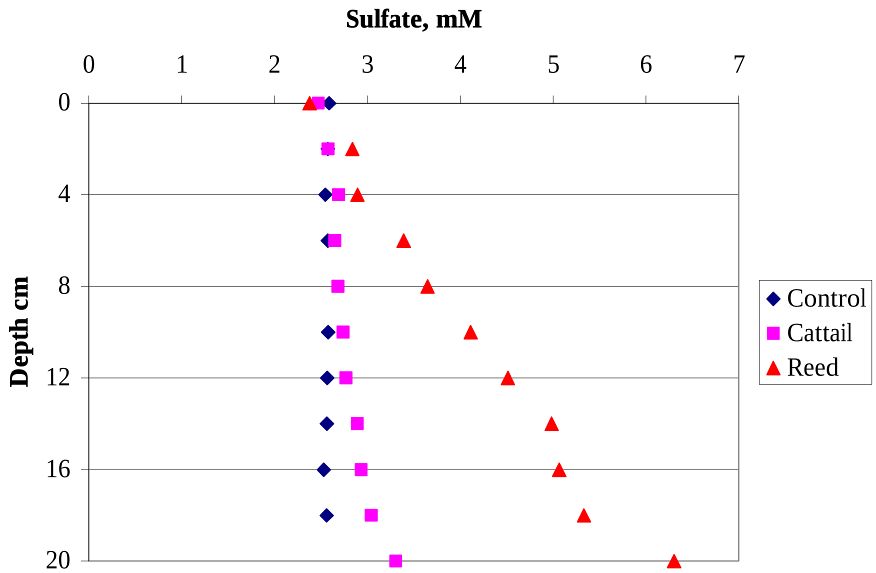


Figure 3. Profiles of pore water sulfate

Given the high load of sulfate to these microcosms and given that sulfate reduction was not observed and sulfate uptake by plants is negligible compared to the loading, sulfate wads used as a conservative tracer in these studies. Bromide and chloride were evaluated as tracers, but results showed a significant uptake of these species by plants. Synchrotron analysis further showed that bromide in the plants as such and did not get converted to organic bromine.

We selected chromium as a trace metal of significant environmental concern, to study its dynamics in wetland sediments. Cr(VI), a widely distributed pollutant from mining and industrial application, is very soluble and has a high mobility in the natural environment. Once reduced to Cr(III), however, it is solubility and mobility is significantly decreased. To study the behavior of chromium in wetland sediment and to assess the effectiveness and pathways of Cr(VI) reduction and remediation, Cr(VI) was amended to the nutrient solution and its concentration in pore waters was regularly monitored.

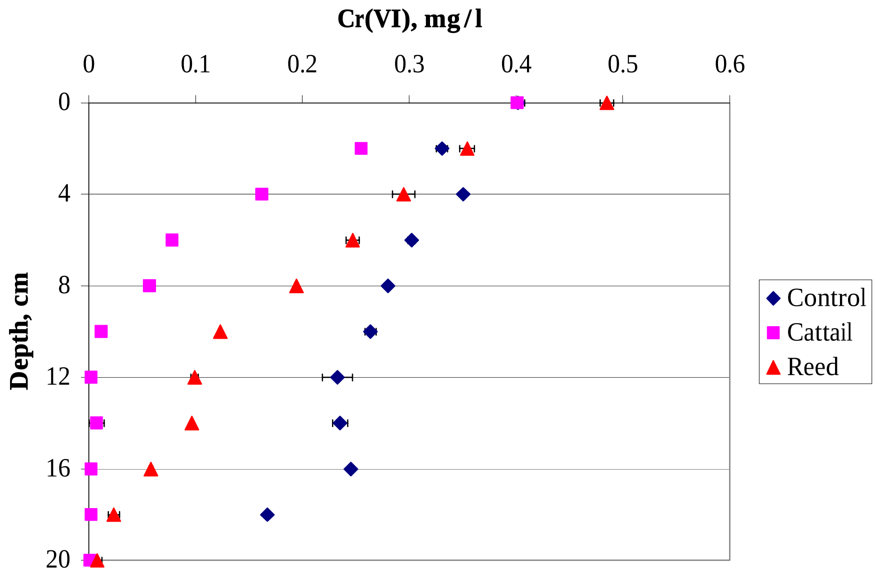


Figure 4. Profiles of pore water Cr(VI)

Results of vertical Cr (VI) concentration profiles in the microcosms, shown in Figure 4, show that a much higher efficiency of Cr(VI) removal was achieved in the planted microcosms, which is attributed to the higher reducing conditions that develop in the presence of the plants. A close look at the Cr(VI) profiles, taking into account the concentration process induced by plant transpiration, revealed that Cr(VI) removal rates were proportional to its concentration in the dissolved phase and the removal coefficients (reduction plus plant uptake) were much higher in planted microcosms (Fig. 5).

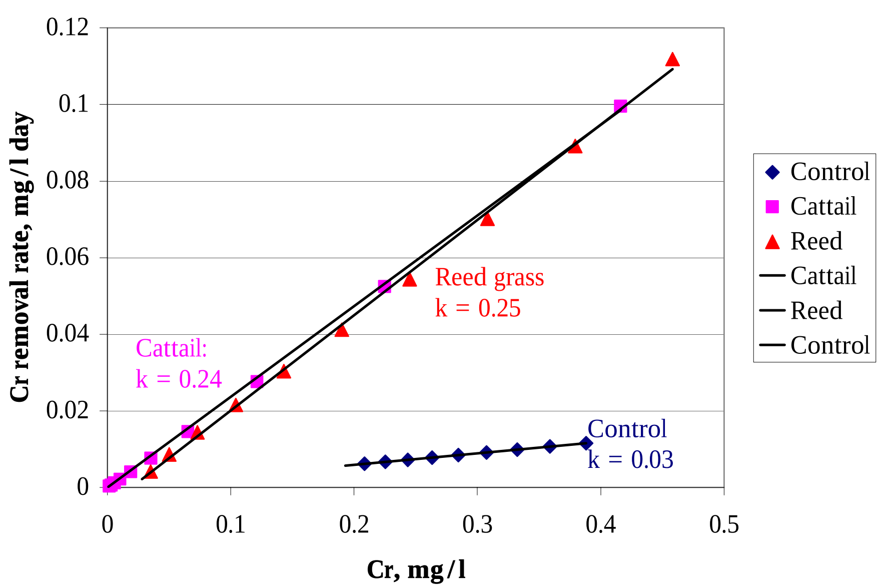


Figure 5. Removal rates of Cr(VI) in planted and control microcosms

To generalize these results, we have developed a mathematical model that simulates the biogeochemical changes that occur in wetland sediments. This model is based to a large degree on our experimental findings, and we have used it to assess how wetlands affect the removal of other species of concern, such as arsenic from contaminated waters entering into surface waters.