Biofilm remediation of Aluminum, Iron and Manganese using “microchip wetland” Metal Removal Units (MRU’s)

by Colin A Lennox, CEO, Lead Researcher

Incorporated in 2010 and active in acid mine drainage since 2012, EcoIslands LLC has installed, tested and refined our patent pending Metal Removal Units on six geographically and chemically distinct sites throughout western Pennsylvania. These MRU’s remove Total Iron, Aluminum, and Total Manganese from impacted waters to below Total Maximum Daily Loads (TMDLs) as secondary or tertiary treatment steps, bringing existing systems into compliance.

MRUs are referred to affectionately as “microchip wetlands” due to the high density of their treatment volume in comparison to current constructed wetlands, requiring considerably less space and cost for the same amount of passive treatment. Double blind protocols for sampling and testing were observed at each site throughout the three plus years of testing.

How Metal Removal Units (MRUs) Work

Metal Removal Units (MRUs) are modular wetlands that promote the growth of large volumes of microbial biofilm which pull dissolved and precipitating metal loads from impacted waters. Like Lego blocks, MRUs can be arranged in multiple patterns and scaled to accommodate mineral loading and flow rate. This modularity is important because no two affected sites are the same, nor are removal rates of aluminum and iron the same as rates for manganese or other metal or nonmetal ions.

Metal/non-metal ion removal is achieved through a combination of biotic “sticky” adhesion and biologically aided oxidation/reduction reactions. The design of the MRU passively and continuously replenishes oxygen through a series of manifolds and waterfalls connecting compartmentalized stepped treatment cells. The aerobic (and/or anaerobic) biofilm that grows in the MRUs is naturally self-selective, meaning that the specific microbial diversity present in the biofilm is dependent on the concentration and reductive/oxidative state of the metal and nonmetal ions.

The biofilm structural matrix (coconut coir) through which the water flows functions as a flexible endo-skeleton, supporting a rapid biofilm attachment phase and constant, natural biofilm growth throughout treatment. As the precipitating metal load accumulates it provides more surface area for biofilm growth as well as an enriched microbial population to deal with incoming metal ions.

The inter-cellular signaling intrinsic to the biofilm and organisms that thrive in the highly aerobic, loose fiber environment of the MRU creates beneficial biologic agitation. Just like worms in soil, higher order organisms involved in the predation and physical disturbance of the bio/matrix complex include micro and macro invertebrates, salamanders, tadpoles and fully grown frogs. This bio-agitation promotes a metal oxide rain that slowly falls, aided by downward water flow, to the bottom of the MRUs where it minimally compresses in the void space designed for that purpose. The self-cleaning, constantly renewed bio/matrix complex allows for more precipitate capture and retention, reducing maintenance frequency and plugging issues. The same cannot be said for the static waterfall/flush manifolds, which is resolved by bi-annual or quarterly maintenance.

Coir is inexpensive and made mostly of lignin, which is difficult for microbes to utilize as a source of carbon, so it lasts for years in pH 7 water.

MRU’s are buried to the top rim and pipes are insulated during construction to allow for greater ground heat exchange and freeze protection. During the summer months the water passing through the MRUs is geothermally cooled and during the winter the depth of the tanks prevent freezing. During the months of Jan-Feb 2015, the Eagle Site system (2 MRUs) removed Mn at 20-30 gpm to TMDL’s (average 3 mg/l to 0.3 mg @ pH 7) without evidence of freeze or ice plugging. The nighttime air temperature was as low as -15F/-26C.

The colder the water, the better. Cold water has higher oxygen saturation which helps to satisfy chemical and biological oxygen demand related to the biofilm and dissolved metals. Faster flowing water provides more O2 and doesn’t have time to freeze during the MRU’s brief retention/treatment time (25-37 minutes = 20-30 gpm, on average). Also, minimum flow rates must be observed, if little or no flow is present during winter months, extra care must be taken in burying the boxes to prevent freezing. Lids are added for safety, security and to provide additional insulation during the winter. Hay and tarp blankets are also added to provide further insulation during winter operation.

Iron

Total Iron (dissolved and precipitating) removal range is pH 2-7 and is mediated by the filtration capacity of the bio-matrix complex and the corresponding bio-mass to MRU volume ratio (more biomass = more bio-filtration through adhesion). The constantly re-supplied oxygen allows for the full oxidation of Fe2 and Fe3 (COD). The Iron Hydroxide floc (yellow-boy @ pH >4) is captured by the biofilm, reducing the outflow Iron concentration to below TMDLs.

One of our key discoveries is that manganese will not bio-oxidize at pH 7 until all ferrous iron (dissolved) and even ferric iron (precipitate) are roughly between 0.42 and 3.0mg/l. This phenomenon is under investigation, but so far appears to hold up throughout biologically based AMD treatment systems, natural, constructed, or MRU.

Aluminum

Dissolved aluminum oxidizes to aluminum hydroxide (Al(OH)3), a sticky floc that is readily adsorbed to the living mass of the biofilm. This adhesion is aided by the positive ionic charge of the Al(OH)3 and the generally negative charge of the biofilm. A properly scaled and maintained system will passively remove Al(OH)3 to less than 0.087mg/L year round. Re-dissolution of aluminum hydroxide due to high pH >8.5 is no longer a worry because manganese, normally requiring a pH of >8 for abiotic oxidation, will bio-oxidize at pH 7 and below in an MRU system. It is not yet known what the upper range of Al removal might be using an MRU and, subsequently, the maintenance frequency. MRU influent water at Gaber Brown 2013 and Albert 2014 rarely exceeded 2 mg/l Al.

Manganese

Dissolved manganese is bio-oxidized to manganese dioxide (rancieite, Ling, F. samples taken from Glasgow MRUs in 2014) by a consortium of Mn oxidizing fungi and bacteria (Santelli, et al.). This biologically catalyzed oxidation occurs at or below 7pH with an influent temperature range from summertime ambient down to just above freezing. Other operational characteristics for bio-oxidation of manganese include: the presence of a source of organic carbon to feed the Mn oxidizing fungi from upstream wetlands, other MRUs, anaerobic compost tea reactor, or the coir itself, Total Fe app <0.35mg/L, and flow rate of 1-30 gpm for a paired series of MRUs (one after the other).

The highest single MRU observed rate of biofilm aided Mn oxidation was 281 grams Mn/day/meter square (Glasgow 2013). Four samples (n=4) averaged 23mg/l Mn removed after 4-5 weeks of system growth and acclimation.

“{[5 (gal/min) \* (23 mg Mn/L)]/24 ft^2) \* (1/1000) (g/mg) \* 3.78 (L/gal) \* 1440 (min/day) \* 10.76 (ft^2/m^2) = 281 (g Mn/d\*m^2). We examined 8 conventional limestone-based Mn removal beds and calculated GDM values of ~2 – 10 (g Mn/d\*m^2) (see Santelli et al. 2010). Your unit is 28 – 140 times better than any of those!” (W. Burgos, 2014, email correspondence concerning Glasgow calculations.)

In Closing and Next Up

MRUs are a cost effective means to remove dissolved and precipitating metals from impacted waters, achieving and/or exceeding stricter TMDLs. We are currently exploring the relationships between the coir dissolution and manganese oxidation rates related to biogenic hydrogen peroxide and manganese peroxidase in order to explain the Glasgow and Flight 93 Memorial rates of Mn treatment observed.

For consultations, site visits, or professional or educational presentations please contact: colin@ecoislandsllc.com, 814-937-9115, Altoona, PA, [www.ecoislandsllc.com](http://www.ecoislandsllc.com)

We would like to thank Bentley Development Co Inc., Ben Franklin Technology Partners, Cambria County DEP, The Blair County Chamber of Commerce, and The Blair County Conservation District for all their guidance and help in getting us this far. Together, we do good work, thank you.

Bibliography

Lennox, C. (2013). Iron and Manganese Reclamation using BioHaven® Wetland Reactors, Results from 2012. Pennsylvania’s Abandoned Mine Reclamation Conference, 2013.

Ling, F. (2015). email correspondence concerning MnO2 samples taken which will be included in doctoral dissertation. (2015-16).

Santelli, C., Webb, S., Dohnalkova, A., & Hansel, C. (2011). Diversity of Mn oxides produced by Mn(II)-oxidizing fungi. *Geochimica Et Cosmochimica Acta,* 2762-2776.

Santelli, C., Pfister, D., Lazarus, D., Sun, L., Burgos, W., & Hansel, C. (2010). Promotion of Mn(II) Oxidation and Remediation of Coal Mine Drainage in Passive Treatment Systems by Diverse Fungal and Bacterial Communities. *Applied and Environmental Microbiology,*4871-4875.