

Constructed Remedial Wetland Design – Not a “Cookie-cutter” Approach

Tim Boudreau¹, Sebastien Marquis² and J Russell Finley^{1*}

¹Pario Engineering & Environmental Sciences, Environmental Division, 40 Thornhill Dr. Unit 12, Dartmouth, Nova Scotia, B3B 1S1, Canada

²MRI: Marquis Remediation's and Innovations, Lower Sackville, Nova Scotia, Canada

Introduction

Constructed wetlands have been used in the last 35 years for the treatment of mine drainage, barn wastes, feedlot runoff in agricultural operations, urban storm water runoff, various industrial wastewater treatment applications, and in the secondary and tertiary treatment of municipal sewage [1-3]. The use of man-made wetlands is on the rise regarding agricultural (mink, swine) effluents and municipal sewage. However, these systems are typically simplified to focus on only one compound of concern (eg: nutrients), often with other contaminants being discharged. A large gap appears to exist between the knowledge available and the application of a multi-faceted approach, possibly as a result of inexperience or the perception of high costs.

Far too often the authors have seen the “cookie-cutter” approach where monocultures of wetland plants are stuffed into a simplified pond construction resulting in a failure to meet the required goals. A sustainable, effective wetland needs to mimic the natural system that taps into the biological remedial attributes [4]. The positive results from our case study add to the growing weight of evidence that success is highly dependent on a multi-faceted wetland design. The design needs to fit the community (and long-term goals) and not the other way around (Figure 1).

A man-made wetland was considered the best, long-term solution for the remediation of residual petroleum hydrocarbons following the mechanical clean-up of 39,000 liters of waste oil inundating a 1000 m² swamp. Our multi-faceted wetland design consisted of a three-celled, free surface water wetland functioning to remove residual hydrocarbons (and metals) as well as improve overall water quality prior to emptying into a nearby river system. Here, we present the justification for a multi-faceted wetland design for remedial approaches with a case study as an example.

The Biomimetic System

When properly designed, the multi-faceted approach will result in Bio-mimicry. Seen simply as the science of replicating nature, it is important to realize, there are no templates in bio-mimicry; every challenge and every site, will dictate the design.

A Biomimetic System is described as a complex assemblage of natural mechanisms, replicated with a specific purpose in mind. These mechanisms may include phytoremediation, bioremediation, mycoremediation (an emerging field), bacterial and macro-invertebrates interactions, natural landscape replication, and food web re-introduction, to name a few. As a result, any wetland design needs to consider remedial objectives, timelines, substrate, soil chemistry, hydrology/geomorphology, vegetation, presence of endangered species or critical habitat, wildlife, cultural/socioeconomic impacts, and the toxicity, fate and transport of the contaminants of concern [4]. Other critical parameters may include specific microsystems, region, climate and seasonality or territorial history.

It is therefore necessary, not only to have a wetland specialist,

but individuals who are an authority in their field and who hold experiential knowledge. Such specialists should include; a hydro geologist to evaluate the aquifer boundaries, flow patterns and volume; a geologist to determine the lithology of the soil and bedrock and relevant thickness; a botanist with a focus on local, indigenous species, phytoremediation and mycoremediation; an ecologist to ensure the wetland reflects the local environment; and an engineer to assist with the design. All of these experts must work seamlessly to produce a multi-faceted approach that will incorporate the three pillars of sustainability; social equity, economics and the environment.

Failure to follow this approach implies a lack of understanding for the processes involved that can and does, result in numerous problems such as, low seed production, impedances to natural plant colonization, the proliferation of insects and other pests, odours, unsightly spaces and ultimately, failure of the system.

In contrast, a properly designed wetland will be aesthetically pleasing, is relatively inexpensive to construct and operate, is effective, reliable and ecologically sound, is relatively pest free, operates year round, provides suitable habitat for wildlife, and is easy to maintain.

Case Study – Constructed Wetland Design to Treat Petroleum Hydrocarbons

This case study presents an alternative, multi-faceted approach that incorporated the expertise of numerous individuals with a primary goal for the long term remediation of hydrocarbons (and metals).



Figure 1: Photo Left shows typical water treatment lagoon with cattails (and some rush) compared to a highly diverse remedial wetland on the right.

***Corresponding author:** Russell Finley, Pario Engineering and Environmental Sciences, Environmental Division, 40 Thornhill Dr. Unit 12, Dartmouth, Nova Scotia, B3B 1S1, Canada, Tel: 902-466-7890; E-mail: russell.j.finley@gmail.com

Received June 01, 2015; Accepted August 18, 2015; Published August 29, 2015

Citation: Boudreau TM, Marquis S, Finley JR (2015) Constructed Remedial Wetland Design – Not a “Cookie-cutter” Approach. J Pet Environ Biotechnol 6: 251. doi:10.4172/2157-7463.1000251

Copyright: © 2015 Boudreau TM, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Background

In 2010, a highway accident, involving a tanker truck, resulted in the release of nearly 39,000 litres of waste oil and other liquids into a floodplain area that included a 1,000 square metre swamp. Although 4,000 litres had migrated beyond the impacted area, the remaining 90% was contained in and around the natural wetland.

Impacted material removal occurred until site limitations prevented physical clean-up to meet jurisdictional compliance with residual hydrocarbons exceeding the environmental criteria. The objectives for the wetland were to:

1. Remediate residual hydrocarbons (and metals) in the area;
2. Compensate for the loss of the former swamp; and
3. Improve ponded water quality prior to entering the downstream river system.

Based on these objectives and prior to determining the design, information relating to local biological, physical and chemical data was collected for incorporation into the wetland. Following construction and establishment, of the wetland community, the effectiveness of the biological, remedial processes were to be monitored over a two year period. This process required knowledge of how each plant employed and would remediate the contaminant of concern.

An integrated remedial approach

Under direction of the botanist, field research targeted organisms for a biomimicry, or whole-ecosystem, approach [4]. Local organisms were selected within a 20 km radius of the area of concern, from three general environments; terrestrial, riparian and aquatic and for their known ability to remediate hydrocarbons (and metals) [5,6].

This integrated approach had emphasis on the following remedial processes:

1. Bioremediation using aquatic and terrestrial microbial assemblages;
2. Mycoremediation using fungal species; and
3. Phytoremediation incorporating uptake and sequestration, phytovolatilization and rizo-degradation.

Only, after a survey of the plants had been completed, was data collected by the assembled, expert team evaluated to obtain the optimum wetland design (Figure 2).

Secondary benefits from integrated process

As part of the sustainable, low maintenance design, a few organisms were transplanted for secondary attributes of nutrient enrichment (peat moss and straw), land stabilization (fast-growing plants), biodiversity, and bio-markers (species highly susceptible to contamination). In some cases the detailed knowledge of botanical attributes allowed for certain species to have multiple functions/purposes which included insect and mosquito control.

In total, 25 different plant species, 4 fungi and 5 tree species were transplanted in the three environments. 75% of these were for their remediation abilities and 25% for secondary purposes. Examples of hydrocarbon-remediating plants used were wild carrot (*Daucus carota*), willow (*Salix spp.*), bulrush (*Scirpus spp.*), cattails (*Typha spp.*), and American water plantain (*Alisma subcordatum*) to name a few [7].

Wetland construction

Having determined which plants would provide the best remedial effects, the physical plan of the 3-celled wetland was tailored by a hydro-geologist to obtain the optimal flow. This required directing surrounding surface water into this wetland and incorporating 10-year precipitation events into the long-term plan. Under the assumption that water would contain residual hydrocarbons, separate factors considered for the considered critical for the intended function of each cell included:

1. Consideration of different physical features to promote settling;
2. Terracing, to allow for separate depth requirements of the various plants;
3. Specific shape, bank slopes and volume;
4. Retention times to ensure proper exposure to remediation vegetation; and
5. Specific biological assemblage for intended functions that would allow for natural colonization;

Cell #1, with the longest retention time, was designed to capture and precipitate the bulk of the contaminants via flow reduction and



Figure 2 : Terrestrial zone.



Figure 3: Establishment of cattails to reinforce flow reduction / sedimentation as well as for HC degradation.

sedimentation features (riffles) and. Incorporating sinuous flow, it consisted of banks of moderate to low slopes to invite run-off from the source area. Bank heights were extended above the anticipated high water level along the remaining sides, except at the outfall (Figure 3).

Cell #2, similar to Cell #1 encouraged sinuous flow over multi-terraced beds and consisted of an oval-shaped, low-sloped, shallow pond containing the majority of the remediative species. This physical shape promoted settling while ensuring a large surface area for interactions with key plant species.

Cell #3 consisted of an oval shaped polishing pool, with most botanical specimens specific to improving the quality, based on chemistry, to acceptable surface water standards. From here water was discharged directly into the nearby river system.

When completed, the total area of the constructed wetland was 1,350 m², this included the three open water cells, overflow swales and the riparian and terrestrial bank, which is 26% more than the former swamp it replaced (Figure 4).

Monitoring program

Between November 2010 and November 2012 routine monitoring was used to assess the functionality and performance of the wetland. This included a physical inspection of wetland features and biological elements as well as collection of sediment, water and plant tissue for remedial performance.

In the first year of monitoring, hydrocarbon (lube oil) levels were described as low to moderate with few samples exceeding applicable criteria whereas all 2012 samples complied with the guidelines. When comparing media concentrations, water significantly ($p=0.05$) decreased and sediment showed a moderate decreasing trend. These results aided in gaining environmental clearance for this site by provincial and federal regulators ahead of schedule!

From its inception, field inspections of the wetland noted only two issues with the cells concerning functionality. From June to July, 2011, a drought caused extremely low water in the wetland during initial, critical growth stage of aquatic plants. The second functional issue was significant proliferation of iron-bacteria (*Thiobacillus ferrooxidans*) in Cell #1 that blocked the outflow swale and coated aquatic plants. Routine inspection of the wetland site allowed for critical maintenance

to rectify noted issues in a timely manner before collapse of the system [8,9] (Figure 5).

Inspection of biological elements at the wetland was used to evaluate botanical survivability and mortality, natural colonization, wildlife usage, and the general health of the ecosystem as a whole. In the first year (October 2010 to September 2011) the plants obtained a 45-90% survivability rate, depending on the type, with an average of 75%. Two species were found to be incompatible with the conditions present with a survivability rate less than 55%; these were not re-planted (Figure 6).

Observation of wildlife (actual presence or scat and tracks) around the wetland is considered a biomarker that the habitat is suitable for colonization (i.e. healthy). At the conclusion of the monitoring program, wildlife counts had increased from 6 to 11 species for aquatic invertebrates, from 4 to 5 for amphibians were identified and mammals had gone from 2 to 4 species.

Summary

A review of our case study indicates the design and implementation of integrated phytoremediation and bio-augmentation programs was successful in naturally processing residual, petroleum hydrocarbon contamination. The wetland was designed for remedial functions emphasized by local, natural plant communities and were reinforced by hydrological features incorporated in the construction. Based on long-term, visual inspections of the wetland community and sample results of environmental media, the constructed wetland is functioning as a low maintenance, long-term solution for contaminant removal in areas where accessibility and costs were an issue (Figure 7).

Secondary advantages that were provided by the implementation of this remediation project include:

1. Increased amount of data into the regional scientific community

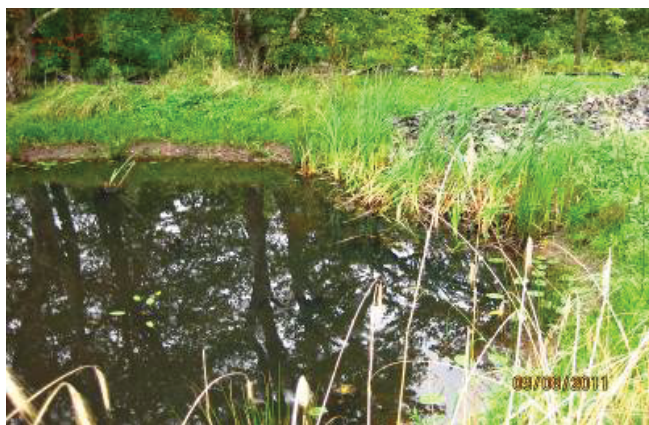


Figure 4: Riparian zone.

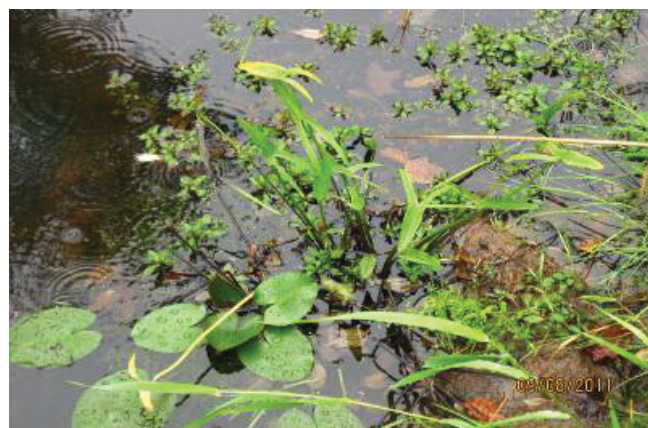


Figure 5: Aquatic zone.



Figure 6: Showing temporal changes with Cell 3 (looking north) of the constructed wetland October, 2010 - September 2012.



Figure 7: Physical hydrological features under construction in Cell 1 on October, 2010.

where such remedial wetland projects are lacking;

2. Increased understanding of integrated, multifaceted remedial methods for future usage;
3. Promotion of natural colonization to increase local biodiversity;
4. Providing compensation (1.4:1) for the loss of the original natural habitat; and
5. Enhancing the area for local wildlife.

The effectiveness of this multi-faceted project supports the relevance of “design to fit the biology” not “fit the biology into the design”. The “cookie-cutter” approach may indeed work for simplified objectives such as storm water management ponds; however, the more complex the goal, the more complex the wetland system. This case

study show, when properly designed, a multi-faceted approach, can be cost effectively applied to a complex problem.

Wherever possible the wetland should incorporate the three pillars of sustainability, social, economic and the environment. This requires the input from a diverse team of experts, capable of understanding the complex, site specific conditions that are designed for the plants incorporated into the constructed wetland.

References

1. Stantec Consulting Ltd (1999) Guidance Manual for the design, construction and operation of Constructed for rural applications in Ontario. Research and Technology Transfer Group.
2. Kamath RJ, Rentz R, Schnoor JL, Alvarez PJJ (2004) Phytoremediation of hydrocarbon-contaminated soils: principles and applications. Dept. Of Civil Engineering, Seamans Center, University of Iowa, Iowa City, Iowa, U.S.A.
3. Galbrand C, Lemieux IG, Ghaly AE, Coté R, Verma M (2008) Water Quality Assessment of a Constructed Wetland Treating Landfill Leachate and Industrial Park Runoff. American Journal of Environmental Sciences 4: 111-120.
4. United States Environmental Protection Agency-USEPA (2000) Guiding Principles for Constructed Treatment Wetlands: Providing for Water Quality & Wildlife Habitat. Developed by the interagency workgroup on constructed wetlands.
5. U.S.EPA (1999) Free Water Surface Wetlands for Wastewater Treatment; A Technical Assessment. Office of Wastewater Management, U.S. EPA, Washington, D.C.
6. Environment Canada (2002) Phytorem, Green Solutions for Contaminated Sites. Phytoremediation Reference Database. Environmental Biotechnology Applications Division. Hull PQ.
7. Benyus JM (2002) Biomimicry: Innovation Inspired by Nature. Published by Library of Congress, New York.
8. Sherameti I, Varma A (2011) Detoxification of Heavy Metals, Soil Biology 30: 243.
9. Stamets P (2005) Mycelium Running: How Mushrooms Can Help Save the World.