Liquid Waste Management Plan
Technical Memorandum

LWMP Technical Memorandum #9

TO:	Wastewater Advisory Committee
SUBJECT:	Effluent Polishing by Biochar Reed Bed
DATE:	January 17, 2018
Prepared By:	Paul Nash, Project Coordinator
Reviewed By:	Troy Vassos,

1.0 BACKGROUND

The concept of "effluent polishing" generally refers to passive or natural means of treatment occurring after conventional wastewater treatment, and is typically intended to further remove remaining dissolved organics (BOD) and nutrients (phosphorus and nitrogen). Cumberland's large facultative stabilization pond is an example of effluent polishing as there is no mechanical components that require maintenance or methods to control or influence the degree of additional treatment received.

Because of the lack of controls or adjustments, effluent polishing is generally applied as a secondary measure to improve effluent quality and serve as an additional barrier to the release of contaminants to the environment in the event of incidental water quality exceedances. Incorporated into the design of a wastewater treatment process these polishing stages serve as a means to better ensure the required water quality will be met.

However, planned effluent polishing can also occur after a regulated discharge, and may not be needed to meet regulatory requirements. The natural wetlands located downstream of the lagoons are a good example, as the water quality of the lagoon discharge to Maple Lake Creek continues to improve and achieve an extremely high quality as a result of uncontrolled natural processes within the wetlands – "polishing" the lagoon effluent.

A constructed wetland is not, strictly speaking, applied as an effluent polishing component. Constructed wetlands are engineered processes designed to replicate and optimize biological, physical, and chemical treatment that is achieved when water passes through a natural wetland. There are well established design guidelines and criteria for constructed wetlands to provide secondary and tertiary wastewater treatment, and levels of treatment comparable to mechanical treatment processes, and are highly engineered systems designed to achieve specific treatment objectives. The concept of constructing wetlands to provide wastewater treatment for Cumberland is not new – this was the preferred treatment option developed in the Stage 2 LWMP in 2006 – and consisted of large areas of emergent system of open water ponds with various floating and fixed vegetation thatches, and was designed for secondary treatment and stormwater handling.

The proposed reed bed concept is a constructed engineered wetland consisting of plants growing in porous media, where water flows through the media and plant root zone below the surface, and there is no free water surface. To differentiate this constructed wetland from the natural wetlands surrounding, and downstream of, the lagoons, the more descriptive term of "reed bed" has been adopted.

The concept of effluent polishing by the reed bed, incorporating charcoal media, was developed as part of the November 2016 funding application, with the intention of incorporating the reed bed within the overall conventional treatment process with specific treatment functions in terms of BOD, suspended solids, and emerging contaminants removal, and with secondary objectives of carbon credits and aesthetics.

With the re-examination of all treatment options, the reed bed stands as a discretionary treatment element that can be added on to any of the main treatment options, as and when desired. Although it can be incorporated into the overall lagoon-based or mechanical treatment process, it can also be incorporated as an “add-on” polishing stage following a regulated discharge.

2.0 TYPES OF TREATMENT WETLANDS

A constructed wetland is an engineered bacteria-mediated ecosystem that is specifically designed for water treatment purpose.

They typically have a shallow containment basin (0.5 to 1m deep) that is filled with support media (typically gravel) and planted with a variety of wetland plants. As the water moves through the system, the biological activity of the plants, and biofilms on their roots and the support media, extract nutrients and organic compounds from the water, thus “polishing” it as it moves through the system. The design and the flow regimes of wetlands can be engineered or controlled to achieve a number of treatment objectives.

Treatment wetlands can be grouped into three main designs, in increasing order of complexity.

1. “Surface Flow” where the water level is above the ground surface, and moves horizontally amongst the plant stems, with negligible flow beneath the surface. This is analogous to flow through shallow natural swamps.
2. Subsurface flow, where the water flow path is through the root zone of the porous media. There are two types of subsurface flow wetlands;
    a. Horizontal flow, where the water flows horizontally from one side of the wetland to another. This is analogous to water entering a stream by filtering through the root zone of the bankside vegetation.
    b. Vertical flow, where the water is dispersed at the top of the wetland and flows downwards through the root zone to a drainage layer. This is essentially the same as watering a potted plant.

Some diagrams of wetlands are shown below (source: Tilley, E., Ulrich, L., Lüthi, C., Reymond, Ph., Zurbrügg, C. - Compendium of Sanitation Systems and Technologies - (2nd Revised Edition). 2014 Swiss Federal Institute of Aquatic Science and Technology (Eawag), Duebendorf, Switzerland.)

Figure 1 Surface Flow Wetland

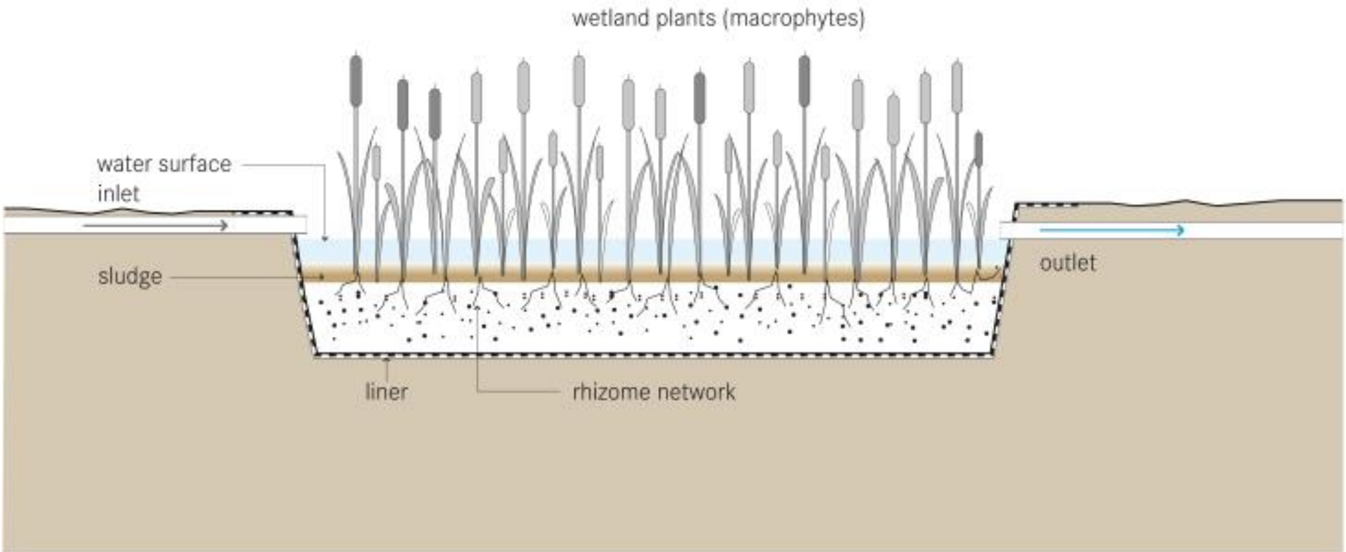


Figure 2 Horizontal Flow, Sub-Surface Wetland

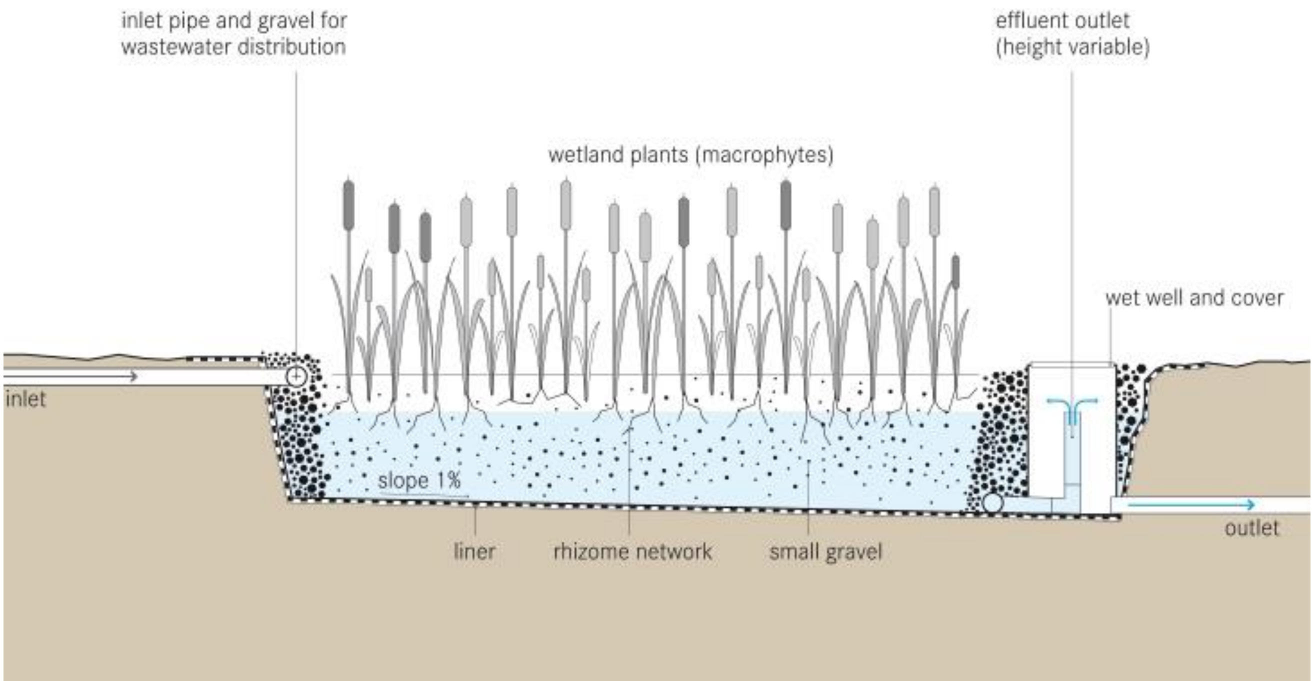
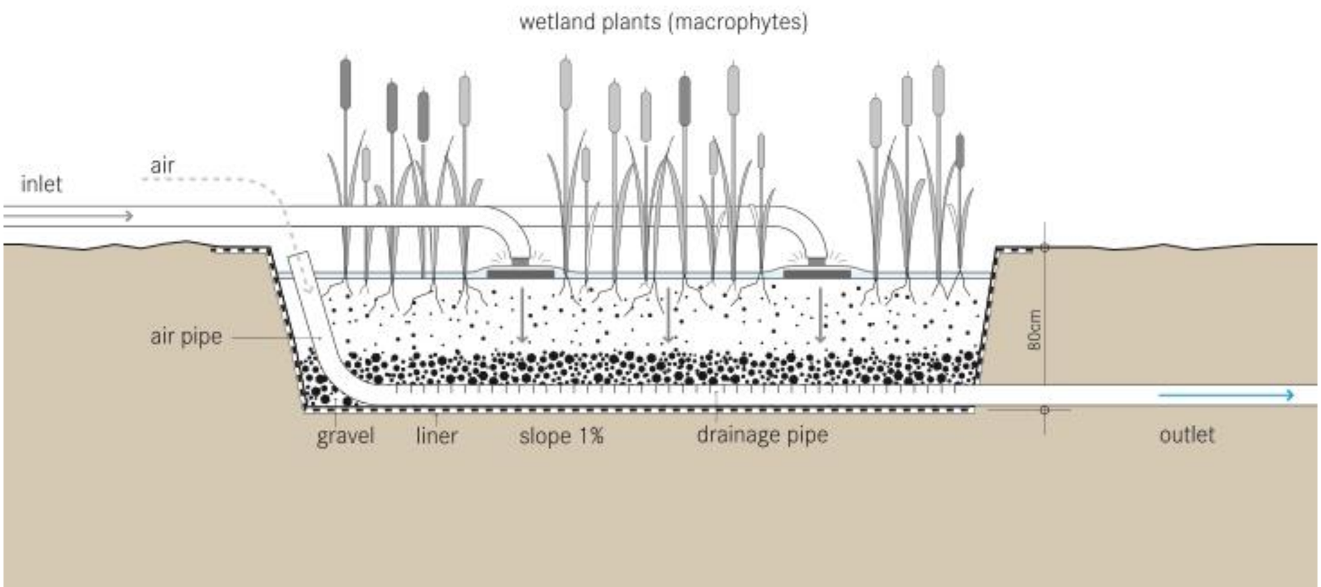


Figure 3 Vertical Flow, Sub-Surface Wetland



A comparison of the properties of the different types is given in Table 1.

Table 1 Comparison of wetland types

Wetland Type	Surface Flow	Horizontal flow, sub surface	Vertical flow, sub surface
Treatment quality	good	better	best
Cold weather performance	fair	best	good
Potential for insects	moderate	low	low
Ease of installation	easy	moderate	intricate
Relative flow capacity	moderate	low	high
Media type	Can be natural ground	porous	porous
Maintenance	low	low	low
Ability to add aeration	no	yes	yes
Land area requirement	large	moderate	small
Relative cost (excl. land)	low	moderate	high

3.0 GOALS FOR CUMBERLAND WASTEWATER TREATMENT

In June 2016, The Cumberland Wastewater Advisory committee developed a series of goals for the wastewater treatment system. There were mandatory goals, set by regulation, and "aspirational goals" representing desirable, but not necessary outcomes. An ideal solution achieves all the mandatory goals and as many of the aspirational goals as possible.

The aspirational goals largely reflected the goals contained within major planning documents, such as the Village of Cumberland Official Community plan, and the Comox Valley Sustainability Strategy. Several of the goals are only partially achieved by conventional wastewater treatment:

- Reduce Energy Use and GHG's
- Innovation/Environmental leadership
- Support health of waterways with robust treatment
- Use of existing ecosystems to control cost including low tech solution and or bio solutions plus beneficial use of produced biosolids
- Sustainability, Climate Change resilience/adaptation/robustness
- Reduce manmade toxins

These goals combined are worth 18 of the 20 points for Environmental goals, an 18% of the overall evaluation. There was a strong desire from the committee to have a system that would action some or all of these goals.

There is an additional benefit in that most of these goals are also provincial and federal government objectives, and are evaluation criteria for infrastructure funding programs.

In pursuing innovative and aspirational goals, the challenge is to not compromise the mandatory goals. An ideal solution in this case would be some element that could be added on to any wastewater treatment system, and action these goals without compromising performance or reliability, and at reasonable cost.

The concept of the biochar media reed bed was developed specifically to meet this challenge and address all these aspirational goals.

In all cases engineered treatment wetlands have a high density of plants and minimal or no open water areas. It should be noted that these wetlands are a highly engineered system designed to perform a specific function. They are not to be confused with "habitat wetlands" that have deeper water and large open areas, and are for encouraging aquatic life and waterfowl.

The type of wetland that is proposed to be used for the Cumberland reed bed is the vertical flow type. This will give the highest flow throughput for the lowest area, and likely the lowest construction cost. The following sections are based on the vertical flow, sub surface configuration.

4.0 WETLANDS FOR WASTEWATER TREATMENT

Constructed wetlands can be used to perform a variety of wastewater treatment functions, including primary, secondary, tertiary and polishing treatment and for sludge drying and composting. Small scale wetlands are also used as an alternative to conventional drainfields for domestic septic systems. The higher the biological load on the wetland, the larger it needs to be, and the more often that accumulated solids need to be removed.

For these reasons, wetlands are most commonly found on small systems and in tertiary or polishing functions, where the biological load is small. That said, there are some very large treatment wetlands. The world's largest is 700ha and treats 115,000 m3/day of oilfield wastewater in Oman.

The treatment wetlands can be designed to performs some very specific wastewater functions. If the objective is removal of BOD and TSS then forced aeration and/or very large areas are required, as is a means of removing accumulated solids. For this reason, wetlands are rarely used for doing the "heavy lifting" of primary and secondary treatment.

For tertiary treatment and polishing, the organic loads are much lower and other functions can be optimized with the design and operation of the reed bed. Specifically;

- Nitrification is the bacterial process of converting ammonia to nitrate. The surface area of the plant roots and media all provide space for growth of nitrifying biofilms within the wetlands. If aerated water is supplied to the reed bed, or if it is aerated by subsurface aeration, then it can be very effective at nitrifying.
- Denitrification is the bacterial process of converting nitrate to atmospheric nitrogen. This is done in anaerobic conditions, and with a carbon source. The bacteria feed on the carbon and get their oxygen from the nitrate. Reed beds can be designed to have an anaerobic zone, or be operated in batch fill and drain mode, or have intermittent aeration, or be operated in series aerobic and anaerobic to achieve this function. One study for the US Army Corps of Engineers found that simply replacing gravel media with woodchip media dramatically improved denitrification performance. (link at http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1148&context=usarmyceomaha)
- Phosphorous removal can be accomplished in sub surface flow wetlands by augmenting the media with phosphorous adsorbents such as zero valent iron, dolomite, lanthanum and others. Surface flow wetlands are generally not suited to phosphorus removal as it is absorbed in the biofilm on plant stems and the plants themselves, and eventually reaches a steady state where no more is adsorbed. Some free surface wetlands exhibit seasonal uptake and release of phosphorus as plants grow and die back. The Maple Lake Creek natural wetlands exhibit this seasonal summer uptake and winter release of phosphorus, which is why they can still absorb 97% of the phosphorus load in the summer
- Pathogen reduction occurs naturally within the soil, and the plant roots encourage competing biota, which further reduces pathogens
- Removal of colloidal and some dissolved constituents by bacterial and plant activity
- Aesthetic functions – a well designed wetland looks good!

Wetlands have the additional features of being low maintenance, low operational complexity and zero energy, or low energy in the case of aerated wetlands. When used for effluent polishing after tertiary treatment, the wetland has an almost indefinite life without getting clogged from solids accumulation, as the plants gradually absorbed the captured biological load.

5.0 REMOVAL OF EMERGING CONTAMINANTS

Treatment or emerging contaminants was discussed in TM#8, with two of the mechanisms being adsorption and biodegradation. There have been numerous studies showing biochar can achieve meaningful reductions, through both adsorption and biodegradation.

Engineered wetlands are less known for removing emerging contaminants, but there have also been several studies showing they can achieve meaningful treatment, with biodegradation being the prominent mechanism. There are more variables with wetland systems – the flow regime (vertical, horizontal or surface), flow rate/residence time, plant types, temperature etc. A field study on pharmaceutical removal from a seasonal release, wastewater polishing wetland at Grand Marais in Manitoba studied removal of some common pharmaceuticals and showed that it achieved good removal of some, such as Carbemazapine (anti- epileptic drug), and not others, like sulfamethxazole (an antibiotic) and gemfribrozil (cholestorol drug) (link at https://ccj.springeropen.com/articles/10.1186/1752-153X-7-54). Other studies have confirmed that wetlands do not remove sulfamethoxazole – however – it is well removed by activated carbon and biochar. A side note is that the Grand Marias wetland also removed phosphorus from an influent concentration of 0.4mg/L to an outlet concentration of 0.007mg/L or <0.005mg/L – thus meeting the same level as the in-stream objective for the Trent River.

Some further studies have looked at improving the performance of wetlands by using adsorptive media such as peat, woodchips, activated carbon and biochar. These studies have found improved performance for removal of EDC's, other organics and heavy metals, though the performance varies with the media type. Adsorptive performance can be further enhanced by adding specific adsorbents such as zero valent iron, dolomite and others.

6.0 FULL SCALE EXAMPLE – PORT OF TACOMA

While most studies on biochar media wetlands are laboratory or pilot scale, a full scale implementation was done in 2013 by the Port of Tacoma. (link at http://aapa.files.cms-plus.com/AwardsCompetitionMaterials/Tacoma 2014 Comprehensive Environmental Management.pdf).

The project was for filtration of contaminated runoff from a log yard. After doing techncology comparisons and field trials, it was determined that a multi stage, vertical flow wetland, with a biochar media stage, was the most economical and sustainable way to treat the contaminated water. The project was constructed and commissioned in 2013, and has been very successful, winning an industry award in 2014.

From the project report (link at https://www.portoftacoma.com/news-releases/2014-11-19/innovative-treatment-system-exceeds-water-quality-rules)

> The system measures 600 feet long by 45 feet wide and was completed in 2013, it moves stormwater through four cells. Each targets a particular pollutant:
>
> - In stage one, pea gravel removes solid pollutants.
> - In stage two, sand amended with biochar removes fine solids, metals and organic contaminants.
> - In stages three and four, the bioretention mix of sand and compost is planted with bamboo and other vegetation to remove the remaining pollutants through biological uptake in the plants.

To date, the system has yielded impressive results, removing more than 92 percent of pollutants:

Parameter	Influent (mg/L)	Effluent (mg/L)	Permit (mg/L)
Turbidity	58.4	9.4	25
Total suspended solids	42	3.5	100
Copper	33.9	12.5	14
Zinc	57.4	8.8	117
Chemical oxygen demand	290	85	120

The cost of the system was relatively high at US$2.4m. Much of this is due to the design of the system, which involved a series of concrete tanks, and each one requiring a pump station to lift the water to the next. The cost of the actual wetland within – media, drainage and plants, was a relatively minor part of the total.

Even though this system is not intended to remove pharmaceutical type compounds, it is likely that it would if they were in the incoming water. The system is clearly working well, and is a good example to draw from.

7.0 CARBON SEQUESTRATION

There is a general desire for reduction in carbon emissions and greenhouse gas (GHG) emissions, to lower the "carbon footrprint". BC municipalities are required to annually quantify and report their emissions, and achieve carbon neutrality, through the Climate Action Revenue Incentive Program (CARIP). This is done by carbon reduction actions, and buying carbon credits to make up for remaining emissions. Part of the evaluation of wastewater treatment options will be the carbon footprint of each one.

Wastewater treatment is typically energy intensive, and it is always desired to reduce energy use and GHG emissions in new wastewater projects. But even the most efficient system is still "carbon positive". And it was expected that any new system for Cumberland will use more energy than the existing one, thus raising overall GHG emissions. In order for a wastewater treatment system to reduce Cumberland's overall emissions, the system itself would have to be carbon negative, and there no known examples of such a system.

Biochar is mostly carbon, and is made from natural carbonaceous sources, typically wood waste but also from other organic waste including animal manures and, most recently, *wastewater biosolids*. The production of biochar in itself releases carbon, but since all the feedstocks are natural carbon sources (not fossil fuels) they are considered carbon neutral to start with, and so are any carbon emissions. This is the same principal that applies to use of biofuels.

Thus, biochar is a carbon neutral product, but what is needed is a carbon negative product, or process. When biochar is applied to the ground, as a soil amendment, it remains in the soil permanently. A large portion of it, called the "fixed carbon", is effectively non-biodegradable. Various studies, such as the the Eurochar study have shown the life of charcoal in the ground is hard to determine, and the half-life estimates ranged from 70 to 145 years, and a mean residence time of over 600 years, though other studies have suggested indefinite soil life. On a human timescale, over 100 years is considered *permanently sequestered*.

If the fixed carbon was 100% of the mass of the biochar, and all the biochar stayed in the soil indefinitely, then the CO_2 credit would be that of carbon itself, i.e. 3.67tCO_2/t biochar. The Eurochar study found 1.59 ton CO_2 per ton of biochar (sourced from forest residue), equivalent to a fixed carbon content in biochar of 43.3%. During the actual production of the charcoal, the fixed carbon can be explicitly measured and quantified, and a common design assumption is 50%, leading to a carbon credit of 1.83 tons of CO2 per ton of biochar sequestered.

To be considered sequestered, the biochar must remain in the ground. If it is used as a reed bed media, it will be there for 10 to 20 years, or longer. If the media needs to be replaced, the biochar can then be applied elsewhere as a soil amendment, and is still considered sequestered. If the biochar is considered “contaminated”, and disposed of into a landfill, it would most certainly have been permanently sequestered.

In BC, there have not been any projects, or even a methodology developed, for officially verifying carbon negative (sequestration) projects. This would need to be done before any official carbon credits could be given to the project.

For this planning stage, the reed bed has been modelled as follows;

- Area to be 17,000 sq.m and 1m deep
- Bed volume = 17,000 cu.m, normally filed with coarse gravel
- Substitute charcoal for 20% of bed volume, 3400 cu.m of charcoal
- Bulk density of charcoal is 250 kg/cu.m, gross weight = 850tons
- Fixed carbon content of biochar at 50% by weight.
- CO2 sequestration 3.66 tons CO2 per ton of fixed carbon.
- Total CO2 sequestration 1,555 tons

For calendar year 2015, the net CO2 emissions for the Village of Cumberland were 52 tons of CO2. If they were to remain at that level, the biochar would offset the emissions for the next 30 years.

There is clearly great potential for carbon sequestration by the production and use of biochar.

8.0 IMPLEMENTATION AT CUMBERLAND

Cumberland is a good opportunity for a polishing reed bed, as the final water from the treatment process will be of sufficient quality to discharge to either the creek or the natural wetlands, so it is also good enough for a polishing reed bed before going to the natural wetlands and the creek.

The proposed approach is to integrate two treatment processes (wetland and biochar) by putting biochar into the plant support media, thus maximising the treatment performance. Table 2 below compares the treatment functions of a treatment wetland and biochar filtration.

Table 2 Treatment comparison of wetlands and biochar filtration.

Treatment Function	Engineered Wetland	Biochar Media Filtration	Combined Performance
Suspended Solids	***	*	***
Nitrification	***	*	***
Denitrification	***	*	***
Phosphorus	**	*	**
Endocrine Disruptors	*	***	***

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Dissolved organics	*	***	***
Colour	*	***	***
Odour	*	***	***
Heavy metals	*	***	***
Aesthetic	***	*	***
Carbon sequestration	neutral	negative	negative

It is apparent that the two processes complement each other very well, each providing something that the other does not.

An interesting possibility that arises with the use of a vertical flow wetland is the concept of a combined vertical and surface flow wetland in high flow or stormwater conditions. If engineered correctly, the normal vertical flow pattern can continue, while excess flow is introduced at the surface, to flow across the surface through the plant stems. This surface flow acts in the same ways as “rain gardens” for municipal stormwater, slowing the flow of water and trapping and settling fine suspended solids. In the case of Cumberland, the vertical flow portion would be designed for the “base flow” and excess (winter) wet weather flows, after disinfection, could surface flow across the wetland prior and then “overflow” to Maple Lake Creek. This will be studied further as the wetland concept is developed.

For an implementation at Cumberland, the concept is to;

- Build the reed bed to the north of the lagoons, with earthen-bermed walls
- Potential area of up to 17,000 sq.m (to be determined)
- Use a vertical flow configuration
- Use biochar for a portion of the media (actual % to be determined)
- Plant with a variety of wetland plants, preferably native
- Send the treated water to the reed bed only after it has been disinfected and met all the regulatory water quality requirements for environmental discharge
- Send the polished water from the reed bed to the natural wetlands to the north, from where it will naturally migrate into Maple Lake Creek

The land area to north and east of the lagoons was extensively studied from 2002 to 2008, with the original intent being to have the wetlands as part of the secondary treatment process. The land was given to the Village of Cumberland under the Federal “Eco-Gift” program in 2002, and use of these lands for a treatment wetland has already been approved by Environment Canada, in 2003.

The proposed layout of the system is illustrated in Figure 4, with the Reed Bed and Wetland Areas 1 and 2 corresponding to the area approved by Environment Canada for treatment wetland purposes.

Figure 4 Reed bed and Wetland Concept

At this concept stage, there are still several unknowns to be resolved before a project can proceed, or even be meaningfully budgeted. These include:

- The source and cost of the biochar and gravel media
- The practical size of the reed bed
- Construction considerations – excavation, berms, piping etc

Budgeting of a project is difficult when there are so many unknowns. For the 2016 project funding application, a budget of $1.9M was used ($1.5M +25% contingency), with the theory being that the reed bed would be as large as possible within that budget. After identifying some real world examples of constructed wetlands being built for $0.5 to $2M, a “placeholder” budget of $1M has been adopted as at January 2018.

There clearly needs to be more detailed study and a meaningful budget estimate before a decision can be confirmed to proceed with the biochar reed bed.

9.0 SUMMARY

The biochar media reed bed represents an innovative combination of natural (wetland) and engineered (biochar) processes.

Both these systems have been proven in separate situations, and there are some field trials in and one full scale use of this combination. The result is a high performance, low maintenance system that removes a variety of contaminants that the conventional wastewater treatment system does not.

The biochar component results in substantial carbon sequestration that, if validated and accepted by the authorities, would make the entire wastewater facility carbon negative for its operational life. This would be the first documented carbon negative wastewater facility in the world.

The biochar media reed bed has the potential to address almost all the Wastewater Advisory Committee's Environmental Goals, and is the only one that is carbon negative. It also makes for a good prospect for funding under federal and provincial infrastructure funds, and environmental leadership funds.

Since the reed bed is not needed for meeting regulatory requirements, its use at Cumberland is therefore entirely discretionary, and it can be added to any treatment system, at any time.

It is recommended that;

- this option remain on the table,
- be studied further to develop an implementation concept, and
- be considered on its own merits for addition to the preferred Treatment Option.