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Wetland Ecosystem Treatment ©1994 Biologic Design Ltd

Integrated wastewater purification, resource production & habitat creation

Wetland Ecosystem Treatment

Water is the most abundant, the most abused, yet the most accommodating of our natural resources. We take for granted the capacity of water to be renewed and purified, largely by natural means. Water distils itself through the sun powered hydrological cycle in which it passes from rain to river, from river to the ocean, ocean to cloud, cloud to rain and rain back to the river again.

It is filtered through the soil and subsoil on its way to wells and springs. It supports a community of animals, plants and bacteria which acts as a biological purification system. This closely integrated community of living things, together with the physical properties of its environment, constitute an ecosystem. This ecosystem is based upon the photosynthetic abilities of plants to absorb solar energy and the power of the microbial population to absorb chemical nutrients from soil and water redistributing them to many diverse life forms.

Wetland Ecosystem Treatment, or W.E.T. Systems function by harnessing the innate ability of wetland ecosystems to absorb and transform the organic nutrients found in wastewater, converting these into plant biomass and soil.

Within the W.E.T. System the natural productivity of wetlands is harnessed creating a purification process which uses the wastewater as a resource, converting waste into yield. As wetlands are the most productive and species diverse ecosystems to have evolved, the potential for a high yield system is great.

Our W.E.T. Systems are not simple Reedbed Treatment Systems or conventional Facultative Pond Systems, although they do contain reeds, as well as a range of aquatic and marginal plants and a variety of willow types and wetland tree species.

The W.E.T. System comprises specially designed and constructed earth banks and ponds. As the wastewater flows through the W.E.T. System, which is densely planted with wetland trees and marginal plants, it is both purified by microbiological action and transpired by growing plants. Up to 40 different wetland species are used in and around the lagoons, ponds and reed beds. Several species of willow, reed and rush are used depending on the type of waste to be purified.

Waste water storage and treatment are combined in these constructed ecosystems which are designed with a large volume and holding capacity. The total hydraulic load is lowered by evapotranspiration and the growing biomass absorbs the organic load. Coppicing the willow on the system keeps it at the peak growth rate enabling the maximum absorption of organic matter, as well as producing a useful harvest of willow each year.

The aims of a W.E.T. System design are to purify wastewater, create a rich, multi-species ecosystem and produce a varied yield. Unlike conventional reed bed treatment, no gravel is used in their construction - soil in the root-zone is the filtration medium.

The basis of the purification process is, as with conventional treatment processes, microbiological; it relies on the biochemical transformations provided by the plethora of micro-organisms found in the soil. In W.E.T. Systems the bacteria and fungi which transform the waste are in a symbiotic, mutually beneficial, relationship with the roots of the wetland plants and trees.

Within this symbiosis the plant roots provide oxygen, sugars and attachment points for the microbes, whilst the microbes mineralise the organic matter found in the wastewater making this available to the growing plants.

When coppiced the trees produce timber or pole wood as well as willow wands which, depending on the varieties planted and the coppice cycle, can be used a source of osier whips for basketry and poles for hurdle making. Pole wood can also be produced for use in creating living willow sculptures and other structures; over a four or five year coppice cycle it can be harvested and seasoned for use as firewood.

W.E.T. Systems become more efficient at purifying the wastewater entering them the longer they are established. This is in distinct contrast to mechanical systems which over time can break down due to mechanical faults and wear on components. The plug flow kinetics of the system give a robust process which is able to cope with shock loading.

The purification processes occur in the soil/root zone and each year new soil is created by the growing plants shedding leaves; so as the system matures and the root zone expands, purification potential increases.

Whilst the number of wetland habitats in the landscape have diminished, W.E.T. Systems provide a refuge for frogs, toads and newts, and shelter for birds, as well as a large variety of insects and pond life.

Depending on the type of wetland ecology which is required and what yields are preferred the final polishing ponds can sometimes be stocked with several species of fish which are a further yield and also act as a biological indicator that the process is functioning well.

W.E.T. Systems are designed for domestic wastewater and many types of agricultural and agro-industrial effluent, including dairy farm yard and parlour washings, silage liquor runoff, cider mill wastes and pig slurry.

In domestic applications the W.E.T. System can be designed and planted as a garden feature including an ornamental or wildlife pond and bog garden.

W.E.T. Systems can be used to treat sewage from individual dwellings of any size, or for treating the wastewater from farms, villages and hamlets instead of using conventional, mechanical, treatment processes.

Biomass type willow can also be planted and used to fuel a combined heat and power boiler and so contribute to the energy needs of the farm, community or dwelling generating the wastewater which 'feeds' the W.E.T. System.

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Treatment processes occurring within a W.E.T. System and a brief description of its microbial ecology

Introduction - description of the W.E.T. System

W.E.T. Systems differ from other constructed wetlands such as conventional Reedbed Treatment Systems and simple Facultative pond systems in a number of ways. They comprise of a number of ponds and planted soil banks. They are also planted with a wide range of marginal and aquatic species as well as a variety of wetland tree species.

Using a series of densely planted ponds and banks of coppiced willow, the plug flow kinetics of the W.E.T. System ensure that settlement and biological treatment occurs over its entire length.

Because the W.E.T. System is a soil-based system, a robust, mixed microbial population is present in the soil from the initial construction of the system onwards. This wide range of soil micro-organisms is able to begin processing the waste immediately, and significant communities of appropriate organisms will quickly develop in response to the wastes entering the W.E.T. System.

The microbial processes that occur because of the soil microbial populations have a significant influence on the internal chemistry of the W.E.T. System. Important transformations occur to the nitrogen content of the wastewater as well as to the iron, sulphur, and carbon.

Outline of the biochemical processes occurring throughout the system and contributing to the purification processes:

Evapotranspiration from the established W.E.T. System

Water levels of the ponds within a W.E.T. System are lowered and thus the effective capacity is increased by evaporation from the water's surface and by transpiration by the planted willow and wetland plants. This evapotranspiration makes a considerable positive contribution in reducing the overall hydraulic load on the W.E.T. System.

Ammonia loss by the system

Volatilisation of ammonia is a physicochemical process described by the equation:

$$NH_3 + H_2O \rightarrow NH_4^{+} + OH^{-}$$

A W.E.T. System has large areas of open water within the ponds. The potential for the volatilisation of aqueous ammonia is greater than within a conventional Reedbed Treatment System with no open water.

This volatilisation process helps to limit the build-up of ammonia within the system which could lead to high concentrations of ammonia causing odour nuisance.

Nitrogen
Nitrogen-containing nutrients present in the wastewater will undergo a series of transformations within the W.E.T. System due to the presence of a mixed microbial population.

Nitrogen is a key element in the W.E.T. System's biogeochemical cycles. Nitrogen occurs in a number of different oxidation states in the W.E.T. System. A number of biological and physicochemical processes can transform nitrogen between these different states.

Several nitrogen transformations therefore occur at all stages within the W.E.T. System.

The major removal mechanisms of organic nitrogen in the W.E.T. System are the sequential processes of ammonification, nitrification and denitrification.

Organic nitrogen is biologically transformed to ammonia nitrogen by mineralisation (ammonification) and by hydrolysis. Mineralisation results as a consequence of the decomposition of organic matter, resulting from actions of both aerobic and anaerobic microbes.

Ammonia nitrogen is in turn converted to nitrite and nitrate through aerobic microbial processes (nitrification). Nitrate nitrogen is further transformed to nitrous oxide or nitrogen gas in anoxic/anaerobic wetland soils by the denitrifying bacteria.

Organic carbon is degraded microbially to carbon dioxide by respiration when oxygen is available and by fermentation under anaerobic conditions. During fermentation organic matter serves as the terminal electron acceptor forming acids and alcohols. Methane can be formed in the soil of the W.E.T. System by the action of bacteria at very low redox potentials.

Ammonification (mineralisation)
In this process organic nitrogen is converted into inorganic nitrogen, especially NH4-N. Mineralisation rates are fastest in the oxygenated zone and decrease as mineralisation switches from aerobic to facultative anaerobic and anaerobic microflora. The rate of ammonification in the W.E.T. System is dependant on temperature, pH, the C:N ratio of the residue, available nutrients in the system and soil conditions such as texture and structure.

The optimum pH range for the ammonification process is between 6.5 and 8.5.
In saturated soils such as those found over a large proportion of the W.E.T. System the pH is buffered around neutrality, whereas under well-drained conditions the pH value of the soil decreases as a result of nitrate accumulation and the production of H+ ions during mineralisation.

Nitrification/Denitrification
Nitrification is usually defined as the biological oxidation of ammonium to nitrate with nitrite as the intermediate in the reaction sequence.

Nitrification is a chemoautotrophic process. The nitrifying bacteria derive energy from the oxidation of ammonia and/or nitrite, and carbon dioxide is used as a carbon source for the synthesis of new cells. These organisms require oxygen during the NH4-N oxidation to nitrite-N, and nitrite-N oxidation to nitrate-N.

The oxidation of ammonium to nitrate is a two-step process. The first step, the oxidation of ammonium to nitrite, is carried out by strictly aerobic chemolithotrophic bacteria, which are entirely dependent on the oxidation of ammonia for the generation of energy for their growth. In soil, species belonging to the following genera have been identified as carrying out these transformations: Nitrospira (Nitrospira briensis), Nitrosovibrio (Nitrosovibrio tenuis), Nitrosolobus (Nitrosolobus multiformis), Nitrosococcus (Nitrosococcus nitrosus), and Nitrosomonas (Nitrosomonas europaea).

Nitrification and denitrification occur simultaneously in flooded soil, in pond basal layers containing an aerobic surface layer over an anaerobic layer, and in the aerobic rhizosphere microsites in an otherwise anaerobic soil.

The probable reaction sequence for the oxidation of ammonia to nitrite by the Nitroso group bacteria is:

NH3/NH4+	Æ	NH2OH	Æ	NOH	Æ	NO2NH2OH	Æ	NO2-
ammonia		hydroxylamine		nitroxyl		nitrohydroxylamine		nitrite

The postulated intermediate compounds NOH and NO2NH2OH have never been isolated, but their participation in the reaction sequence is consistent with the assumption that two electrons are transferred for each oxidation step between NH4+ and NO2- .

The second step in the process of nitrification, the oxidation of nitrite to nitrate, is performed by facultative chemolithotrophic bacteria, which can also use organic compounds in addition to nitrite for the generation of energy for growth.

In contrast with the ammonia-oxidising bacteria, only two nitrite-oxidising bacteria are presently known to be found in the soil, Nitrobacter winogradskyi in soil and freshwater and the genus Nitrospira in soil and marine sediments.

The nitrification process is influenced by temperature, pH, alkalinity, inorganic carbon source, the microbial population and concentrations of NH4-N and dissolved oxygen. The optimum temperature for nitrification in pure cultures ranges from 25 to 350C and in soils from 30 to 400C.

Nitrifying bacteria are very sensitive organisms and are susceptible to a wide range of inhibitors, including high concentrations of ammoniacal nitrogen. A narrow pH optimum range (7.5-8.6) also exists; however, acclimatised systems can be operated to nitrify at much lower pH values.

Denitrification

The first anoxic oxidation to occur after oxygen depletion is the reduction of nitrate to molecular nitrogen or to nitrogen gases. From a biochemical point of view denitrification is a bacterial process in which nitrogen oxides (in ionic and gaseous forms) serve as terminal electron acceptors for respiratory electron transport.

Electrons are carried from an electron donating substrate (usually, but not exclusively, organic compounds) through several carrier systems to a more oxidised N form. The resultant free energy is conserved in ATP after phosphorylation, and is used by the denitrifying organisms to support respiration.

Denitrification can be illustrated by the following equation:

$$6(CH_2O) + 4NO_3^- \rightarrow 6CO_2 + 2N_2 + 6H_2O$$

This reaction is irreversible and occurs in the presence of available organic substrate only under anaerobic conditions (Eh = +350 to +100mV), in which nitrogen is used as an electron acceptor in place of oxygen. Pure culture studies have indicated that nitrate reduction can occur in the presence of oxygen; hence, in waterlogged soils such as those found in a W.E.T. System, nitrate reduction can occur before oxygen is depleted.

Denitrifying ability has been demonstrated in 17 genera of bacteria, with most being chemoheterotrophs, obtaining energy solely through chemical reactions and using organic compounds as electron donors and as a source of cellular carbon.

The genera Bacillus, Micrococcus and Pseudomonas are probably the most important in soils, and in the aquatic environment the most important are Pseudomonas, Aeromonas and Vibrio. Other denitrifiers include members of the genera Achromobacter, Aerobacter, Alcaligenes, Azospirillium, Brevibacterium, Flavobacterium, Spirillium and Thiobacillus.

When oxygen is available, these organisms oxidise a carbohydrate substrate to carbon dioxide and water. Aerobic respiration with oxygen as an electron acceptor, or anaerobic respiration using nitrogen for this purpose, is accomplished by the denitrifier with the same electron transport system.

This facility to function both as an aerobe and an anaerobe is of great practical importance because it enables denitrification to proceed at a significant rate soon after the onset of anoxic conditions (a redox potential of approximately 300mV) without a change in the microbial population.

Because the denitrification process is performed almost exclusively by facultative anaerobic heterotrophs that substitute oxidised forms of nitrogen as electron acceptors in respiratory processes, and because these processes follow aerobic biochemical routes, it can be somewhat misleading to refer to denitrification as an anaerobic process; rather, it is one that takes place under anoxic conditions.

Environmental factors which influence denitrification rates include the lack of oxygen, redox potential, soil moisture, temperature, pH, the presence of denitrifiers, soil type, organic matter and the presence of overlying water.

The optimum pH is between 7 and 8; however, alkalinity produced during denitrification can result in an increase in pH.

Uptake of nutrients by planted species within the W.E.T. System.
Within the W.E.T. System, nitrogen-containing and other nutrients are also taken up by the growing plant population. The potential rate of nutrient uptake is limited only by the range of plants introduced, the net productivity (growth rate) of the planted species and by the nutrient concentration of the plant tissues.

Nutrient storage is similarly dependent upon plant tissue nutrient concentrations and also on the potential for biomass accumulation, that is, the maximum standing crop.

Desirable traits for the plant species used therefore include rapid growth rate, high tissue nutrient content and the capability to attain a high standing crop (biomass per unit area). The plants we use in a W.E.T. System have been selected on this basis as well as for being fodder and habitat species for native wildlife.

The regular cycle of harvesting the W.E.T. System for willow coppice and other planted species, yields a variety of material for crafts use - this has the beneficial result of removing nutrient/biomass from the mass balance equation.