Subsurface Bioreactors as a Possible Addition to Enhance WW Treatment Plant Operation : A Brief Review

ABSTRACT

Prior to the establishment of the United Sates Environmental Protection Agency and the Clean Water Act signed into law in 1972, water treatment was done on a minimal level or was not present at all. Since then, scientists strive to improve and advance new and existing water treatment processes that water can be discharged safely into water bodies.

Constructed wetlands as engineered waste water treatment systems are used today as a final waste water treatment before the treated waste water is released into a water body.

Surface flow and sub terranean flow constructed wetland options exist and are used for the treatment of municipal, agricultural and industrial waste water containing pollutants such as human waste, soap, fats, chemicals, and pharmaceutical compounds.

They can be operated all year round (24/7) at temperatures that might exceed 35°C (95°F) and as low as around -26°C (-15°F).

Constructed wetland systems in general depend on the quality of pretreatment for the inflow waste water, the hydrology and the carrier material as well as the climate, the vegetation and the physical and technical properties of the plant-based sewage treatment plants themselves, as well as the operational principle applied to the constructed wetland system.

Constructed wetland operated as surface and or sub terranean flow mode can be a cost-effective and low-energy consuming alternative that requires only minimal operational effort. Experience shows that sub-terranean flow surface constructed wetland can be a long-term cost-effective solution that operates stable in various hot and cold weather conditions for decades with minimal operational and maintenance effort.

Keywords: Contaminants, constructed wetland, sewage, subsurface constructed wetland, WW, wastewater treatment plant

1. INTRODUCTION

Today providing clean water is one of the significant challenges our world faces in the present and future. Without clean water life is not sustainable.

Historically water pollution in the U.S. was first addressed with the River and Harbor Appropriation Act of March 3, 1899, Section 9 & 10 regulate activities affecting navigation in United States waters, including wetlands, this included limiting the discharge of refuse matter into any kind of navigational waters to better facilitate navigation [1,2]. The discharge of raw sewage and industrial pollution into water bodies was not regulated prior to the appropriation of the Federal Water Pollution Control Act (FWPCA), signed into law June 30, 1948, governing the pollution of the U.S. surface waters [1,2,3].

However, the reliance on natural processes to clean polluted water with residential sewage and industrial waste disposed into rivers, streams, wetlands and lakes was not enough.

In 1969 Oil slick in the Cuyahoga River catches fire on June 22, 1969, causing $50.000 dollars in damages at that time. Apparently, the river had caught fire many times in previous years. In 1952 a river fire caused damage of 1.5 million dollars to an office building and river front boats [4-7]. The fire in 1969 created a national outcry on water pollution leading to the establishment of the U.S. Environmental Protection Agency (USEPA) by a proposal from President Richard Nixon on July 9, 1970. The Agency was established on December 2, 1970, after an executive order was signed by Nixon [8,9,10]. In 1972 the Clean Water Act (CWA) was signed into law on October 18, 1972, with bipartisan majorities in both the House and Senate overwriting President Nixon’s veto [11,12]. Till today, amendments and revisions have been made to the CWA to protect US surface water bodies with the latest in the bipartisan Infrastructure Law in 2021 investing more than $50 billion through established water financing programs of the EPA [13].

Prior to the CWA and after, the movement of increasing environmental awareness, especially in recent decades, lead to new water technology developments to improve water quality, many of them inspired by natural biological processes, which is also called biomimicry.

In the past decades, engineers and scientists have developed systems that can precisely reproduce the functions of natural wetlands. These so-called plant-based Wastewater treatment Plants (WWTP) can be used for a wide range of applications. Some examples are the water purification of polluted rainwater, domestic and agricultural WW (WW), as well as if a pretreatment is applied, on treating compost and landfill leachate, municipal WW, and pretreated industrial WW.

The main focus of this review is limited to the application of plant based WWTP for the treatment and purification of primary or secondary domestic municipal WW based on a system designed and installed at the Village of Minoa in the State of New York.

2. DEFINITION OF CONSTRUCTED WETLANDS

The term "Constructed Wetland" (CW) refers to a technology designed to mimic ecological processes that occur in natural wetlands. These systems use an interaction of wet biotope plants, media, and associated microorganisms to remove or filter contaminants from the WW. CW are WW treatment systems which may consist of one or more treatment cells designed and built in an integrated and semi-controlled environment to ensure optimal WW treatment. As with other natural biological purification processes, plant based WWTP benefits from additional advantages. They are generally reliable systems that do not require man-made energy sources or chemical substances. Furthermore, they require minimal operational requirements and monitoring. Wastewater treatment with this technology also offers the opportunity to create or rehabilitate wetlands for environmental improvement, such as the construction of wildlife habitats, green spaces, and other environmental aspects [14].

3. CONSTRUCTED WETLANDS AS WASTEWATER TREATMENT OPTION

A CW consists of a complicated assembly of different components. The mechanisms thereby available to remove the contaminants in the effluent are consequently numerous and often interrelated. These mechanisms include according to: a) Settling or deposition of suspended matter, b) chemical and physical adsorption, c) filtration and chemical precipitation through contact of the water with the medium, d) chemical conversion, e) adsorption and ion exchange on the surfaces of the plants and the substrate, f) degradation and conversion of pollutants by microorganisms and plants, g) uptake and conversion of nutrients by microorganisms and plants, and h) eliminate pathogens (bacteria and viruses) [15].

CW systems are ecological systems that combine physical, chemical, and biological processes in a controlled system environment and are able to exactly mimic the functions of natural wetlands. A major difference, however, is the degree of control over the natural processes. For example, a constructed wetland works with a relatively stable flow of water through the system, in contrast to the very variable water balance of natural wetlands. As a result, the ecology in CW is burdened with higher concentrations of WW constituents as they would otherwise occur in nature [16].

Nevertheless, it is possible with CW systems to almost completely remove and eliminate a large number of different pollutants from the WW. In particular the 5-day or 7-day Biochemical Oxygen demand (BOD5 or BOD7), Total Suspended Solids or aerosols (TSS), Sediment able Substances (SS), nitrogen as well as metals, trace elements (e.g., phosphorus) and pathogens [16].

4. CONSTRUCTED WETLANDS FOR PRETREATMENT

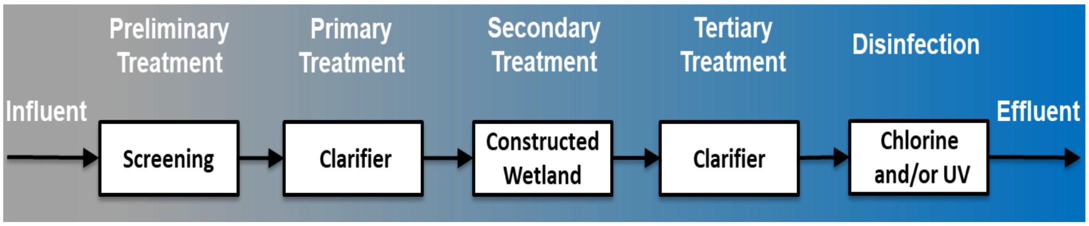
CW are engineered systems, can be a valuable addition to existing WWTPs for the enhancement of unwanted compound removal. They can be specifically designed for the application of treating WW at both decentralized and centralized WW systems to treat: a) stormwater runoff, b) municipal sewage, c) graywater, d) agricultural wastewater, and e) industrial wastewater. Their treatment process needs to be adjusted based on the type of WW used. CW in general use natural processes for treatment which may including organisms and/or vegetation and/or soil, or a combination thereof to remediate the influent WW. However, based on the strength of the WW, primary treatment might be necessary.

CW can be distinguished in two design and operational types: a) subsurface flow (SSF) and b) surface flow (SF). The design of SSF CW utilizes either horizontal flow or vertical flow of WW through the gravel, sand, and or other media, while SF CW utilizes a horizontal flow pattern. In addition, a vertical flow pattern through a CW may reduce the footprint of a CW [15-19].

Today, a CW is a possible alternative for a secondary treatment of raw municipal WW. Figure 1, shows in a simplified process how a CW can be implemented in a WW treatment process, applicable for surface water containing and/or subterranean CW.

In a first step large contaminations suspended in the WW are removed by preliminary treatment using a screening process. The following primary treatment removes large amounts of organic suspended solids or soluble matter, measured as Biochemical oxygen Demand (BOD) and Chemical Oxygen Demand (COD), by flocculation and settling in a primary clarifier. The pre-clarified WW enters the CW as a secondary treatment process. Effluent from the CW is then forwarded to a tertiary treatment process, which may utilize a clarifier. The treated WW from the Tertiary treatment process enters then a disinfecting process step, which may utilize chlorination or Ultraviolet (UV) treatment before the clean effluent is discharged into a waterbody at the WWTP treatment site [20].

Fig 1: Application of a Constructed Wetland Treatment Process [21]



The reason for a screening as a preliminary treatment is to prevent that large unwanted particle such as heavy particles (glass, metal, sand, etc.) and light particles (plastic, styrophoam wood, etc.) as well as other non-digestible (aerobic and anaerobic) material enter the constructed wetland to prevent plugging of the flow pass and/or floating on the water surface for subsurface and surface CW respectively, and therefore reduce associated maintenance costs for a CW [22]. Furthermore, the degree of pre-treatment also influences the quality of the cleaned water at the end of the process regulated by local, state and federal regulatory laws which may require chlorination or UV treatment based on the waterbody the treated water is discharged [17,23,24].

CW acts as a biofilter similar as natural wetlands and can remediate various pollutants including a) organic matter, b) nutrients, c) pharmaceuticals), d) heavy metal, and e) (oil) from the WW. Pathogens such as bacteria, viruses, protozonas and helmints can be removed to some extent, while the removal rate of subsurface CW is greater than for surface CW.

CW might utilize vegetation in the gravel and/or sand filter bed or submerged and/or floating aquatic plants to further improve its remediation function [15,16,17,22].

4.1 Surface- and Subterranean Flow Constructed Wetlands

Surface Flow CW (SFCW) are known as free water surface constructed wetlands and Subterranean Flow CW (STFCW) systems might be used today for tertiary treatment, stormwater runoff treatment or for polishing off effluent from municipal, agricultural, industrial, and decentralized WWTP before the treated WW is released into the environment.

Figure 2 shows for example installed CW types installed for the treatment of a) municipal sewage, stormwater and sewer runoff, and b) decentralized WW treatment system.

Fig. 2: Different Types of Constructed Wetland [25]

Figure 3 shows a principal sketch of a SFCW and STFCW. These systems might be plant-based or not plant based. SFCW can have a combination of submerged plants or floating plants located in the open water surface, while STFCW has no open water part of the CW as shown in Figure 3 shows a principal a. In STFCW, Figure 3b, all WW is kept below the surface of the earth. This makes it possible to walk on STFCW normally over its surface, as it is very well fixed and stable. In terms of appearance, these facilities are more like meadows than swamps or wetlands.

Both SFCW and STFCW systems, as shown in Figure 3, generally have the WW to be treated three zones embedded in a combined or single zone engineered basin that is sealed off with a geomembrane made either from a clay layer, a High-Density Polyethylene (HDPE) foil, concrete or combination of the three is used. This prevents contamination by WW seeping in the surrounding environment.

Furthermore, the Distribution and settling zone in Zone 1 and outlet and collection zone in Zone 3 is backfilled with a suitable level of porous media. Boulders, gravel and or sand are the most used for this purpose [15,16]. Both the distribution and settling, as well as the outlet and collecting zone in Zone 1 and Zone 3 contain a coarse gravel layer in which the influent distribution and collection piping is embedded.

The fill medium, normally gravel, used in the inlet and outlet zones is slightly larger than the gravel used in the treatment zone itself. As a result, these zones do not clog as easily (as would otherwise occur with smaller media). On the other hand, it simplifies the construction and maintenance, because the larger rock in the influent and effluent area serves as a district barrier in the SCW which allows easy removal and reinserting, in the event of a blockage and or if cleaning is necessary. Furthermore, the larger rock in the inlet an accept area allow good water distribution and collection for operational purpose. [16].

Usually, a water level control system such as a weir or wet well is used to adjust the water level in the STFCW and SFCW.

The treatment Zone 1, 2b, and 3, shown in figure 2, is filled with gravel or plastic growth media for the STFCW and may contain vegetation on the surface. The medium in the inlet and outlet zones (Zone 1 and 2) is slightly larger than the gravel used in the treatment zone itself. As a result, these zones do not clog as easily (as would otherwise occur with smaller gravel media). On the other hand, it simplifies the construction and maintenance, because the larger rock in the influent and effluent area serves as a district barrier in the STFCW and or SFCW which allows easy removal and reinserting, in the event of a blockage and or if cleaning is necessary. Furthermore, the larger rock in the inlet an accept area allow good water distribution and collection for operational purpose. [16].

For the treatment section of the STFCW, smaller rocks such as gravel or crushed stone are then used in the treatment zone, as this provides sufficient surface area for microbial growth and thus contributes to better filtering harmful particles out of the wastewater [DAV-98].

For the SFCW treatment Zone 1 and 2 may be filled with gravel or plastic growth media while Zone 2b contains a free water surface. A SFCW might even only be engineered containing only Zone 2b with an influent and effluent structure.

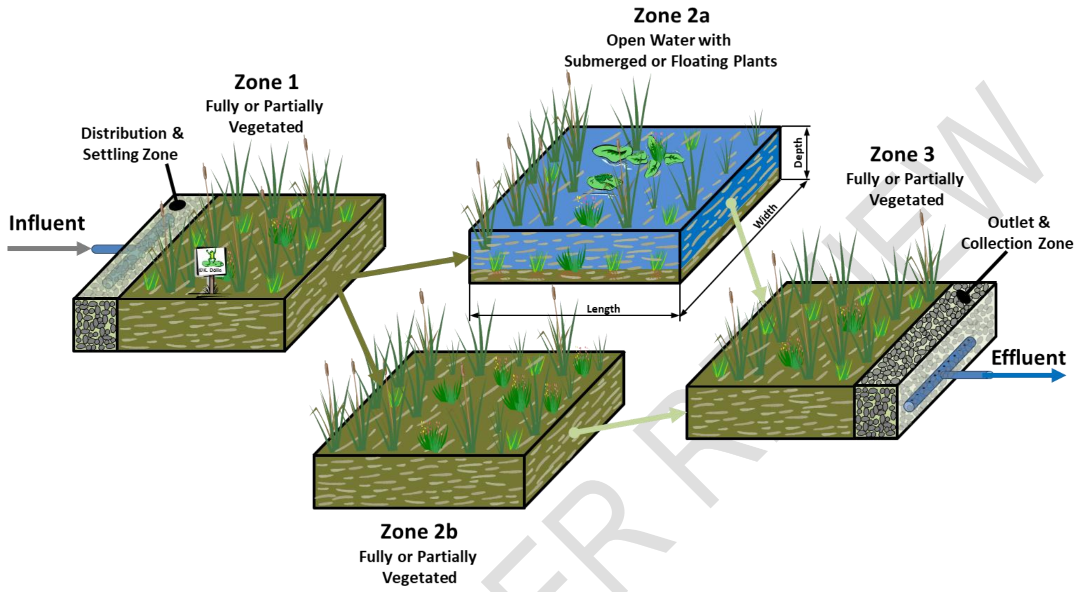


Fig 3: Surface- and Subterranean Flow Constructed Wetland Types [26]

Furthermore, in addition to the shape and size of the SFCW and STFCW system, other variable factors such as the choice of the bacteria growth medium (shape and size of the gravel and or plastic media) as an economic factor and the selection of the right vegetation (if desired) are important influencing factors for the system. Each of these components is assigned different functions and tasks, which are described in more detail on the following pages.

An important factor for an SFCW and STFCW with and without plants-based treatment is primarily the growth material used. Depending on the area of application, different sizes of the growth medium are used.

For the treatment section of the SCW, smaller rocks such as gravel or crushed stone are then used in the treatment zone, as this provides sufficient surface area for microbial growth and thus contributes to better filtering harmful particles out of the wastewater [15].

Finally, the smaller media used in the treatment area of the SCW, serve as a basic anchor element for both the vegetation (phragmites, grass etc.) planted on top the SCW, while the plant roots serve a settling and anchor surface for bacteria and microbes.

The media used primarily influences the root structure of the artificially created flora as well as the remediation ability of the SCW, as shown in Figure 4, allowing the roots of the plants to penetrate the entire tank depth down to the bottom, creating an enormous root system for additional water treatment and uptake of contaminants.

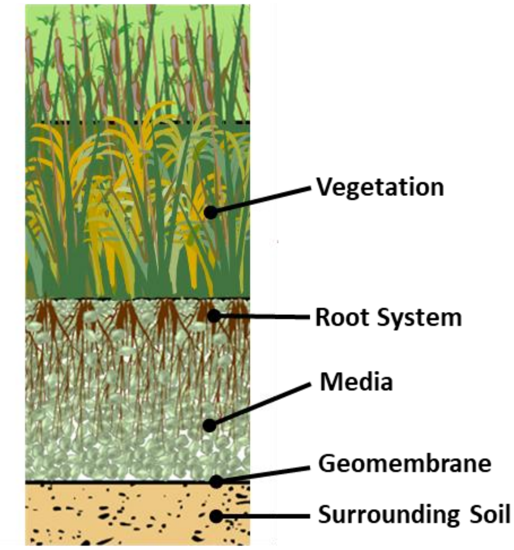


Fig. 4: Scetch of Vegetation in a Subteranian Flow Constructive Wetland [27]

The vegetation used in a SCW is a critical and important part of the process, as the plants used, with their roots, ensure that sufficient oxygen reaches the medium, thereby promoting aerobic microbial growth. Furthermore, they contribute to wastewater treatment in several ways,[15,16]; a)They stabilize the substrates, b) prevent a canalized flow of the WW, c) slow down the existing water speeds so that the suspended matter can settle better, d) absorb carbon, nutrients and trace elements and embed them in their tissue, e) ensure gas exchange between the atmosphere and the sediments of the SCW.

In addition, to the planted, for example reed plants and their roots, have algae growing between them. The algae and root combination of the system is an important factor, because photosynthesis by these algae increases the dissolved oxygen content of the water flowing through the SCW, which in turn has a positive effect on the nutrient and metal removal reactions [15,16].

Hydrology is one of the most important factors and plays a major role in CW, because it connects all the functions of the system. It is therefore often referred to as the primary factor responsible for the success or failure of a plant-based wastewater treatment plant [15,22], and attention must be paid to the following: first, small changes in hydrology can have significant effects on the system and its effectiveness in treatment. Second, dule to the large surface area of the water and its simultaneously shallow depth, the system interacts strongly with the atmosphere such as precipitation, snowfall and evaporation (the combined loss of water through evaporation of the water surface and loss through transpiration of plants). Third, the density of the vegetation influences the hydrology, since the water has to find its way through the existing root network. Fourth, good hydrology provides food and energy for the bacteria in the system.

The design of a STFCW systems, shown in a simple sketch in Figure 5. It is assumed that the water level on the bottom of the system remains below the level of the media used. The water to be cleaned flows a slight gradient horizontally from left to right through the porous medium [28].

This has the decisive advantage that two different types of bacteria are used within the cell. In the front area, where the water flows closer to the surface and is still enriched with oxygen, aerobic bacteria can go about their work. At the same time, the anaerobic bacteria can carry out their function in the rear section since the water level drops significantly there.

This is another essential feature of SCW, because their functions are largely regulated by microorganisms and their metabolic processes. These microorganisms include bacteria, fungi, protozoa and algae. The microbial biomass is an important system component because it can convert a large number of organic and inorganic substances into harmless or insoluble substances and thus filter them out of the wastewater [15, 16]:

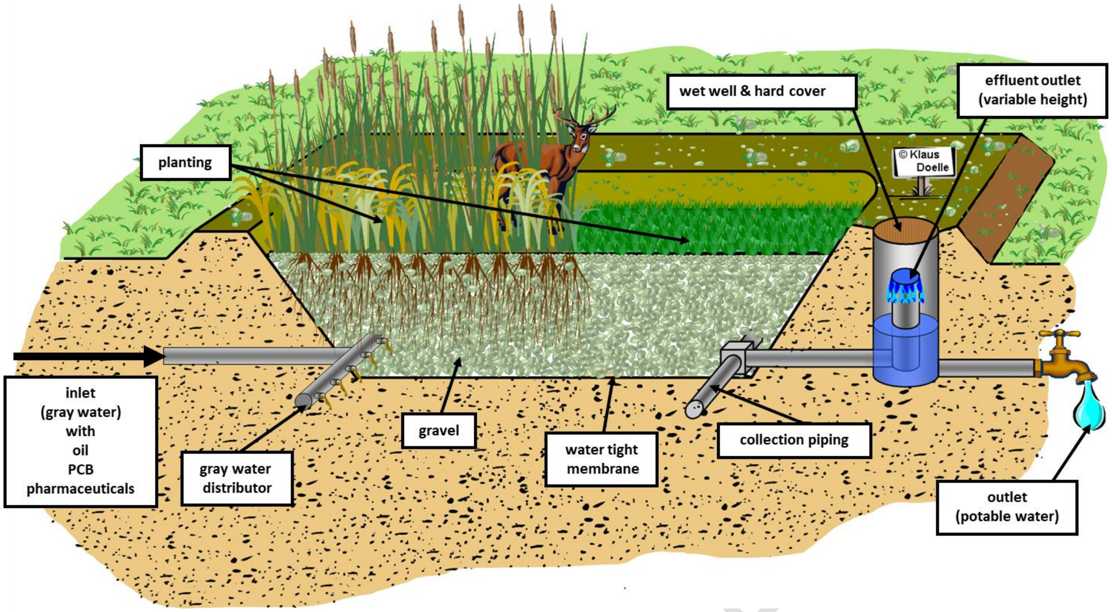


Fig 5: Scetch of a Subterranian Flow Constructed Wetland [22]

For STFCW this is particularly important in converting nutrients such as nitrogen into its multitude of biologically usable forms. For example, different variants of nitrogen are made available in the different phases of the nitrogen cycle. These serve either the plant metabolism or the oxygen can be released or used up as a result.

The Phosphorus uptake by plants also depends in part on the activity of microorganisms, as they convert the insoluble forms of phosphorus into soluble forms that plants can ultimately process better.

The microbe colony in the STFCW process organic (carbonaceous) compounds and release carbon dioxide in the aerobic zones of plant-based wastewater treatment plants, as well as a variety of gases (carbon dioxide, hydrogen sulfide and methane) in their anaerobic zones. This changes the Red/Ox conditions of the substrate and thus affects the processing capacity of the constructed wetland.

As mentioned earlier, some microbes are aerobic, meaning they require free oxygen, while others are anaerobic, functioning only in the absence of free oxygen. However, many types of bacteria in the system are aero-anaerobic and can exist under both oxygen deprivation and oxygen supply and thus adapt particularly well to changing water and environmental conditions. However, microorganisms can be affected by toxic substances such as pesticides or heavy metals. It is therefore important to filter out such harmful chemical compounds from the incoming wastewater beforehand and or during the treatment process.

4.2 Application of a Subterranean Flow Constructed Wetland

At the Minoa WWTF, part of the municipal sewage is treated in the STFCW according to the simple schematic flow chart in Figure 6. Approximately 1.8 million l/d of municipal WW enter the WWTF through an influent structure where a prescreening process removes large impurities via a gravel trap and rake. This pre-cleaning removes leaves, stones, and hygiene items, for example. The screenings can be either pressed, dried, and disposed of at a landfill or converted into energy at an incineration plant [22, 29].

From the influent structure one half of the prescreened liquid sewage volume (900,000 liters per day) is pumped into a Sequential Batch Reactor (SBR) which consists of two alternating parallel tanks that are about 12 ft. (3.7 m) deep, 25 ft. (7.6 m) wide and 50 ft. (15.2 m) long. Each tank operates currently at an alternating 4-hour aeration and settling cycle which aerates and mixes the raw sewage as it fills the first tank with compressed air for approximately two hours prior to two hours of settling. During aeration and settling the biological colony in this tank consumes the organic fraction of the wastewater, reducing the Biochemical Oxygen Demand (BOD) and the ammonia. After aeration, the air is shut off, the incoming sewage is diverted to the adjacent second tank for aeration and mixing and the mixed liquor is allowed to settle in the first tank. After a period of settling, the treated supernatant is removed with a mechanical decanter and passes a chlorination treatment before the cleaned WW is discharged into a stream. The biosolids (primary sludge) from the SBR treatment tanks are collected in a separate tank adjunct to the treatment tanks.

The other half of the prescreened sewage (900,000 liters per day) is pumped to a primary clarifier which is a large settling tank where organic substances are removed from the wastewater by sedimentation by reducing the flow velocity in the primary clarifier. This ensures that substances that could not be removed in the previous treatment steps are deposited. Feces or paper settle in the primary clarifier as "settleable substances" or float on the surface. Around 30 percent of the organic substances can thus be removed from the wastewater. The solid, settled components are also referred to as primary sludge.

Half of the clarified water, approximately 450,000 liters per day, from the primary clarifier is directed into an influent box that feeds the trickling filters. The other half of the clarified water is directed to the STFCW. The STFCW currently consists of 3 cells. Cell 1 operates with a recirculation process. Cell 2 is dormant and can be put into service if needed. Cell 3 operates as a through flow cell receiving WW from Cell 1. All three cells of the STFCW are planted half with grass and the other half with Phragmites. The complex root system of Phragmites and grass in the cells as well as bacteria cultures present help take up nutrients and filter the water. The effluent from the STFCW is redirected into the influent box where it mixes with the 450,000 liters per day primary clarified water. Both the clarified water and the treated SCW water (9000,000 liters per day) is then forwarded for secondary treatment into the trickling filters.

Trickling filter and SBR remove with the help of bacteria and other microorganism the organic WW constituents with the help of oxygen. Special bacteria break down nitrogen compounds.

After the trickling filters the treated WW is forwarded for final treatment into the secondary clarifiers (SC) for settling organic components.

Primary Sludge generated by the PC, SC and SBR Is forwarded into an Aeration Tank (AT), which is a holding tank and biological reactor to which oxygen is supplied. During the holding time bacteria break down the pollutants further till the sludge in the WW of the AT tank is dewatered bi-weekly with a belt press. The resulting solids are dried in a drying field prior to disposal at a landfill. The removed press water is forwarded to the influent structure of the WWTP.

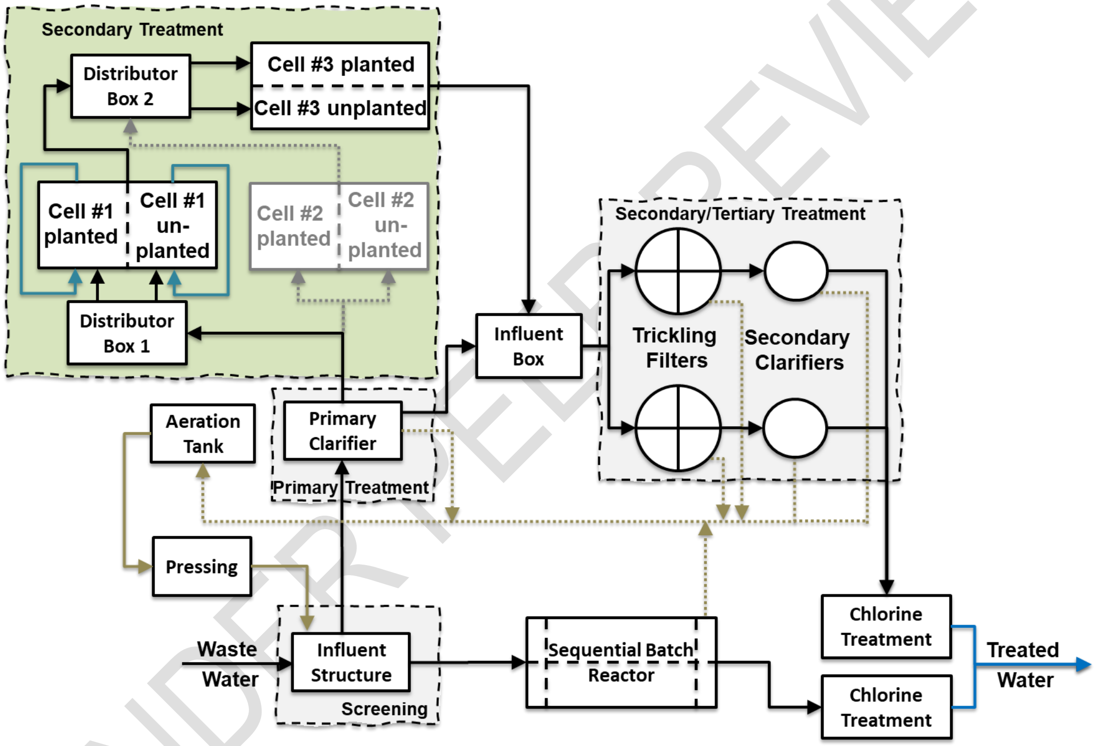


Fig 6: Waste Water Treatment Plant Process Sketch with Subsurface Bioreactor [30]

4.3 Operation of the Subsurface Bioreactor in Minoa

The WWTP Minoa has over 2 decades of operating experience with STFCW under different process conditions. In the past and at present time different operation modes of the three existing STFCW cells were present. For comparison purposes, each cell consists of two halves – one unplanted side (only covered with grass) and one side planted with reeds, the so-called “Phragmites plants”.

The schematic shown above in Figure 6, shows the currently implemented design of the STFCW. The cells can be divided into their pollutant elimination performance.

The STFCW cells in Minoa are 60 m long and 30 m wide. Figure 6 shows a STFCW through flow wetland that treats WW, as well as can treat storm water surcharges through severe weather events and or as containment vessel for unexpected environmental events.

Fig 7: Subterranean Flow Constructed Wetland Cell 1 [31]

On the influent side they are 30 cm (12 in) deep and at the effluent si5e 60 cm (24 in) deep. As a growth medium 50 mm (2.0 in) coarse gravel is used.

The flow volume at which the STFCW is operating is 340,000 to 455,000 liters per day. The third cell, shown in Figure 7 is designed to hold over 7,560,000 liters in an emergency situation.

The STFCW system is operated all year round (24/7) without a break at temperatures as low as around -26°C (-15°F) and as high as 35°C (95°F). Prior to the recirculation flow design of Cell 1, Cell 1 and Cell 2 were operated at a 24-hour fill and drain cycle, also known as tidal cycle (TC). The TC cycle is shown in Figure 8. During the TC one of the STFCW cells is filled from the bottom to the top, the other cell is drained from the top to the bottom with respective a flow gradient shown in red and green. The TC forms a distinct anaerobic anoxic and aerobic layer in the cell. The anaerobic bacteria are managed by adjusting the remaining WW in the cell at a constant level, in order to have anaerobic bacteria convert biocomponents that are diverted down to the bottom of the STFCW and have not been digested previously by aerobic and anoxic bacteria layer.

Today Cell 1 prior TC Cell 1 and Cell 2 connected in parallel serve as the first cleaning stage. They represent the most important wastewater treatment step, as their task is to remove most of the organic pollutants that occur, as well as metals and trace elements. This is followed by a second treatment stage in cell 3 which serves as a through flow cell for nitrification of the WW. The nitrification stage removes nitrogen ammonia using nitrification bacteria. The treated WW that flows from cell three already meets all quality requirements to be discharged into nearby creek.

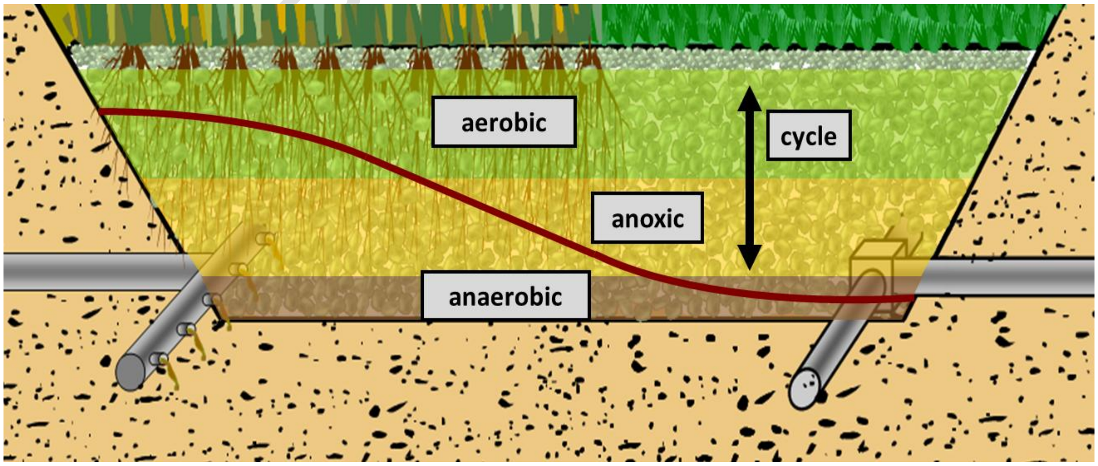


Fig 8: Tidal Operation of a Subterranean Flow Constructed Wetland Cell [32]

However, due to regulatory requirements the effluent of cell three is forwarded to the influent box of the trickling filter where it mixes with the effluent of the primary clarifier.
For the STFCW installed at the WWTP in Minoa the basic treatment mechanisms for pollutants removal from primary residential municipal WW are listed in Table 1 including the removal mechanism for the specific pollutant.

Table 1: Basic treatment mechanisms and their removal of pollutants
P = primary effect, S = secondary effect, N = side effect (occurs in conjunction with the two main effects), Metabolism includes both biosynthesis and various catabolic reactions.

	Mechanisms	Settable Material	Colloidal Material	BOD5	N	P	Heavy metals	Bacteria & viruses
Physical	Settling	P	S	N	N	N	N	N
	Filtration	S	S					
	Adsorption		S					
Chemical	Separation				P	P		
	Adsorption				P	P	S	
	Degradation						P	P
Biological	Bacteria Metabolisms		P	P	P			
	Plant based Metabolisms							S
	Plant based Adsorption				S	S	S	
	Natural Decay							P

These process mechanisms can reduce the biochemical oxygen demand and suspended solids to very low concentrations, thereby significantly increasing the water quality. Furthermore, nitrogen removal to very low levels is possible if sufficient residence time is ensured in the system and enough oxygen is available to support the necessary nitrification reactions. Above all, the many different types of bacteria that can be found in individual cells contribute significantly to their being effective in reducing the trace elements and various metals present. However, the system and its current design has a limited ability to remove phosphorus and additional treatment may be necessary. However, exactly how the entire removal of pollutants works is explained on the following pages [28].

4.3.1 BOD5 removal

Physical removal of BOD5 occurs rapidly through the settling and trapping of solid and suspended matter in the voids of the gravel support medium. This process takes place mainly in the front part of the cell where anaerobic areas exist. Soluble BOD5 is thereby eliminated by microbial growth on the surface of the medium and on the roots of the plants. Compared to other forms of wastewater treatment, subterranean constructed wetlands are unique in that the BOD5 is not only supplied by the incoming wastewater but is also generated within the system by the decomposition of the plant debris and other naturally occurring organic materials itself. As a result, the systems cannot achieve complete BOD5 removal, which is why there is typically always a residual concentration of 2-7 mg/l in the wastewater. The elimination is therefore limited and only feasible to a certain extent. This fact must always be considered when determining the quality requirements for the water to be cleaned and an additional settling or removal process needs to be added [23, 28].

4.3.2 TSS removal

The removal of suspended solids or suspended matter is very effective with SF constructed wetlands. Elimination occurs within the first few meters of entry due to the quiescent conditions and shallow depth of the effluent in the system. A controlled distribution of the feed can help to ensure low velocities for solids separation and ensures an even load in the plant-based wastewater treatment plant. Furthermore, it was found that the TSS removal follows the same pattern as that of BOD5. This suggests that if a system is designed for a certain level of BOD5 removal, the TSS distance to it will always be comparable if the water flow is kept below the surface. As a result, the TSS can be reduced to a level of around 10 mg/l, which corresponds to the specified quality standards [23, 28].

4.3.3 Nitrogen removal

The removal of nitrogen in all its various forms in the system is probably one of the most difficult and complex processes that take place in plant-based wastewater treatment plants such as CW.

Removal of non-ionized ammonium is typically one of the most important nitrogen parameters because of its toxicity to fish and other aquatic animals. For this reason, limits for the ammonium concentrations permitted in water have been introduced and determined in recent years. However, these depend on the quality and degree of contamination of the incoming wastewater and must therefore be adapted to the respective conditions.

The nitrogen entering the system can be measured as either organic nitrogen, ammonia, or nitrate. Organic nitrogen is typically associated with particulate organic WW solids and/or algae. In addition, the naturally occurring organic materials in the facility can also provide a source for organic nitrogen. The cause of this "additional" nitrogen source is probably that the solids are trapped in the foundation due to the anaerobic decomposition of the organic nitrogen. There, the ammonia is oxidized to nitrate, among other things. Furthermore, some decomposition and mineralization processes can transform a significant part of this type of nitrogen. The most important processes involved in removing ammonium are those of biological nitrification, followed by the denitrification step. With this, elimination rates of 60-86 percent can be achieved. It has also been shown that plant-based sewage treatment plants can be controlled to enhance the process of denitrification with carbon sources from the biomass in the system itself. This makes it possible to achieve nitrogen concentrations of less than 10 mg/l in the outflowing water [23, 28].

4.3.4 Ammonia removal

The limiting factor in removing ammonia via nitrification processes is the presence of oxygen in the carrier medium. However, it is not known exactly how much oxygen is provided by the vegetation in SF constructed wetlands or what the oxygen transport efficiency of the different plant species is. Plants, however, transfer enough oxygen to their roots to keep them alive. One disagreement is how much excess oxygen then goes into biological activity in the root end zone. This oxygen is not diffused in the subsurface profile and is therefore available on the surfaces of the smaller roots. The resulting aerobic areas on the root hairs thus offer potential contact surfaces for the nitrification of ammonia. These occur along the entire length of the cell. However, the demand for oxygen needed for BOD5 removal limits the potential for nitrification in the front part of the system [23,28].

4.3.5 Phosphorus Removal

Unfortunately, phosphorus removal is not yet very effective due to the limited contact between the wastewater and the bottom of the tank where the necessary processes take place. However, the potential is enhanced by the presence of iron and aluminum. Thus, if significant phosphorus elimination is desired, then alternative treatment methods are required, such as end-of-process disinfection [23,28].

4.3.6 Metal Removal

The removal of metals in subterranean constructed wetlands is very effective. The dominant mechanisms for their removal are based on precipitation and adsorption phenomena. The precipitation reaction is significantly increased by the metabolism present in the system, since this raises the pH value of the inflowing acidic WW and this therefore reaches almost neutrality. This enables the successful removal of up to 99 percent of copper, zinc, iron and cadmium [23].

4.3.7 Pharmaceutical Compounds

Pharmaceuticals and personal care products (PPCPs), which is one group of “Emerging contaminants” can cause serious problems, because they are widely used and some of them can be harmful to the environment and humans [9] and are carried by WW through the WWTP. If released, they can have a dramatic and disconcerting effect on local wildlife and toxic effects on marine organisms [17].

PPCPs include a large number of chemical substances contained in prescription and over-the counter therapeutic drugs, veterinary drugs, fragrances, cosmetics, sunscreen products, diagnostic agents, and nutraceuticals [22].

A study by Dölle and Qian on Naproxen and Ibuprofen showed that STFCW can remove these compounds in the range of 40% to 95% [17,22]

4.3.7 Conclusion

In conclusion, it can be said that the removal of WW pollutant in a WWTP always depends on the amount and type of contaminants present in the WW which can change significantly during a day’s operation and time of year [22]. The processes used for removal include process performance for removal of the contaminants.

CW systems in general depend in addition of the quality of pretreatment for the inflow WW, the hydrology and the carrier material as well as the climate, the vegetation and the physical and technical properties of the plant-based sewage treatment plants themselves, as well as the operational principle applied to the CW system.

5.0 OPERATION

At WWTP’s the influent WW quality parameters are much dependent on seasonal factors such outside temperature, WW temperature, rainfall, day of the week, etc. and therefore have a certain variance on a daily basis [22]. Therefore, each WWTP component needs to be able to adjust to the ever daily changing WW parameters.

Plant-based sewage treatment plants, such as the Minoa STFCW, can be operated continuously throughout the year. They work both in summer, during cold weather periods, and in winter. For instance, temperatures in Upstate New York can be around 35°C (95°F) and as low as around -26°C (-15°F) during the wintertime.

During the different seasons physical processes such as sedimentation continue to take place independently of the temperature, provided that the water does not freeze completely. This is because many of the reactions take place on the substrate. Even if the ongoing biodegradation and microbial activity are reduced somewhat in winter, both still generate enough heat to keep the subsurface layers of the system frost-free. Influent water temperatures are approximately between 10.0°C and 22.0°C during the year with an average temperature of 15°C. This ensured that the established bacteria colonies do not stop working in the SCW and water does not freeze. In addition, the WW in the SCW is constantly moving which eliminates cold spots that tend to freeze. The Minoa SCW even do not show a snow cover at temperatures around the freezing point, eliminating freezing of the wetlands. Ind addition, snow accumulation serves as a natural insulation layer (iglu-effect) for the wetland preventing freezing of the wetland.

In the wintertime wildlife can be constantly seen I the planted wetland. Wildlife uses the SCW as a hiding spot and resting place due to the higher temperatures of the SCW surface compared to the surrounding areas.

The water treatment can therefore continue to run continuously even if a layer of ice forms on the surface [15].

However, the levels of the wastewater in the constructed wetlands must always be adjusted to the respective weather conditions, which can occur throughout the year. High flow rates, which often occur in winter and spring due to snowmelt, spring rain or a rising groundwater level, ensure that the wastewater flows through the plant-based sewage treatment plant too quickly and may not have enough residence time for adequate treatment. Furthermore, they can lose large amounts of water in summer through evaporation. But even with such calculable inflow rates, the water balance of constructed wetlands must be adjusted weekly or monthly, compared and constantly adjusted [15, 16].

Temperature fluctuations primarily affect the treatment performance of constructed wetlands, although not uniformly for all wastewater components. For some components, this tends to decrease with colder temperatures. However, removal of BOD5 and TSS via flocculation, sedimentation and other physical mechanisms (as noted above) is less affected.

5.1 Monitoring

Unlike natural wetlands, plant based WWTP are designed and operated to meet specific performance standards regardless of their type of STFCW or SCW or a combination off. As soon as these are put into operation, the system must be monitored regularly to ensure or guarantee correct operation, optimal performance and water release requirements set by regulators. Based on the determined results by the monitoring. [EPA-99].

Plant-based sewage treatment plants must therefore be monitored on a set regulatory schedule, such as by weekly certified laboratory testing, to ensure that the discharged water meets permitted values for Total Phosphorous (TP), Ammonia Nitrogen NH_3, Total Kejdal Nitrogen (TKN), Carbonaceous Biochemical Oxygen Demand (CBOD), Total Suspended Solids (TSS) and biochemical Oxygen Demand (BOD) measured in milligram per Liter (mg/l).

Based on the over 25 years of operating experience of the Minoa SCW, it is important that a plant based WWTP systems can perform well over a long time period the following important factors are taken in consideration. First, it should be ensured that the to treat WW has always sufficient contact to take up oxygen before it is treated in the plant based WWTP system, Second, the WW treated always should have sufficient contact with the microbes or bacteria as well as with the bacteria growth medium. Third, the WW should always reach all areas of the plant based WWTP system and dead spots are in the flow pattern should be avoided. Fourth, a healthy environment for the bacteria and microbes is essential for good operation. Fifth, good growth conditions for the vegetation is provided to ensure contaminant removal. Sixth, vegetation is monitored and groomed to avoid overgrowth and rotting. Seventh, the operational staff is well trained and understands the microbiological and technical function of the plant based WWTP system to be able to assess problems and troubleshoot the system.

Overall monitoring is a very important tool, as it provides data to improve wastewater treatment, identify problems more quickly, detect erratic accumulations of potentially toxic substances, and verify compliance with operational requirements. This makes it possible to identify any irregularities or problems that may occur during operation at an early stage. In return it guarantees quick intervention and correction of the system and the associated parameters. The degree of monitoring always depends on the size and complexity of the existing plant based WWTP system. In addition, the control effort can also change over time when the system is more mature, and the individual functional parameters are better known and understood during the startup phase and the first years of operation.

5.2. Maintenance

The maintenance of constructed wetlands takes place at regular intervals and includes the cleaning of the distribution systems and weirs or dykes as well as mowing and inspection of the vegetation work as well as required regulatory system monitoring. Furthermore, it should always be recorded which operators are responsible for the operation and implementation and are therefore responsible for correct implementation and control. Furthermore, the following measures might be taken according to [DAV-98]:

a) Adjustment of the control structures responsible for regulating the water depth
b) Cleaning and maintenance of inlets and outlets and the associated valves,
c) Review of the monitoring devices,
d) Inspection of dams and weirs,
e) Examination of any damage that may have occurred in the overall system,
f) Checking the current level of deposits and whether they need to be removed,
g) Adjusting the water flow to ensure adequate water levels during construction and operation, and
h) Setting the operating range of water levels, including acceptable ranges of variation

5.3. Benefits and Limitations

SCW provide multiple functions and continue to have many benefits. The functions refer to the processes occurring in the system itself and their use to their attributes, which society perceives as an advantage.

5.3.1 Benefits and Advantages

The main benefit of a STFCW is the isolation of animal and human effluent. Since there is no contact with the pathogens in the wastewater, there is no transmission to the surrounding population. This means that these plant-based sewage treatment plants do not have to be additionally fenced off or secured. Furthermore, there is no generation of mosquitoes or gnats because the water level is below the surface of the earth.

In addition, STFCW operated in Minoa have the following other important benefits and advantages, which are: i) CW systems in general are less expensive than other wastewater treatment options in regard to installed costs, ii) Operating and maintenance costs (energy and supplies) are low. For instance, the STFCW at Minoa are designed for gravity flow which requires no additional pumping and therefore saves associated electrical cost, iii) minimal energy required for the operation can be easily generated with solar energy, iv) operation and maintenance require only periodic, rather than continuous, corrective work which allows operators to perform other duties in the WWTP, v) STFCW can be off-line for several month and can be brought back to operational performance in a few days, vi) STFCW are able to tolerate certain water fluctuations and allow therefore to adjust for surges especially if severe weather events happen and WWTP get a higher volumetric influent stream as during normal times, vii) STFCW systems provide habitat for many important insects and wildlife due to their natural vegetational cover, viii) STFCW systems can be built in any shape to blend in with the landscape, also adding aesthetic value to open spaces, ix) STFCW improve water quality using natural processes with minimal or no energy used, x) STFCW can serve as flood or precipitation catch basins for severe weather events or accidents that require storage of large liquid volumes, and xi) STFCW and CW contribute to education and research [15,16,22].

5.3.2 Limits

However, there are also some limitations for the usage of plant based WWTP systems:

In general, i) larger areas of land are required than conventional wastewater treatment systems and are therefore only economically affordable where there is enough inexpensive land available, ii) performance fluctuations can be greater than with conventional wastewater treatment. This is due to their efficiency that might be affected by ever changing environmental conditions, such as the amount of precipitation (rain, snow and ice), temperature, and extended dry periods, iii) the average performance throughout the year can be quite acceptable, that doesn't mean they can live up to quality standards at all times of the year, iv) their biological components are sensitive to toxic chemicals such as ammonia and pesticides, v) a sudden increase in contaminants in the water flow can temporarily reduce treatment effectiveness, and vi) they may require a certain minimum water flow rate if they are to survive. However, while they can tolerate temporary droughts, they do not long survive complete drainage, therefore an if shut down a sufficient water level needs to be maintained [15,22].

6. CONCLUSION

Prior to the establishment of the United Sates Environmental Protection Agency in 1970, and the Clean Water Act signed into law in 1972, water treatment was done on a minimal level or not present. Since then, water treatment has come long ways and many regulations on the State and Federal level protect our water bodies located in the United Sates.

Scientists strive to improve and advance new and existing water treatment processes that contain many process steps that are interlinked with each other before the treated WW can be discharged into a close by water body.

CW as engineered WWTP systems today are used to as a final treatment for WW before the WW is released into a water body and are designed based on natural processes, require a pretreatment of the WW, need minimal operational oversight but and good understanding of the operational staff oof the biological processes involved. They can serve as wildlife habitats, green spaces, and can be used for environmental rehabilitation of ecosystems.

The CW can be designed as either a SF or STF operation or a combination of both, with and without plant cover, depending on the domestic WW that might contain pollutants such as human waste, soap, fats, chemicals, and residues from industrial and agricultural processes, as well as surface water, containing pollutants including chemicals from household detergents from laundry and dishwashing, and pharmaceutical compounds due to medicine use of residents.

STFCW are suited for applications where space is tight and exposure to the WW is not favorable. STFCW systems can be operated all year round (24/7), removing but not limited to compounds such as P, N, NH_4-N, COD, BOD, SS, including pharmaceutical compounds.

Temperatures of operation might exceed 35°C (95°F) and can be as low as around -26°C (-15°F), preventing evaporation and or freezing of the water of which both can jeopardize the WW treatment operation.

Removal of WW pollutant in a WWTP always depends on the amount and type of contaminants present in the WW which can change significantly during a day’s operation and time of year [22]. The processes used for removal including process performance for removal of the contaminants.

CW systems in general depend in addition of the quality of pretreatment for the inflow WW, the hydrology and the carrier material as well as the climate, the vegetation and the physical and technical properties of the plant-based sewage treatment plants themselves, as well as the operational principle applied to the CW system.

Therefore, SCW and SSCW at WWTPs can be a cost-effective and low-energy consuming alternative that requires only minimal operational effort if enough area is available to house the SSCW. Experience at the Minoa WWTP shows that SSCW can be a long-term cost-effective solution that operates stable in various hot and cold weather conditions for decades with minimal operational and maintenance effort.

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