Subsurface-Flow Constructed Wetlands for Water Treatment

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Young bulrush growing in a subsurface-flow constructed wetland.

Subsurface flow (SSF) constructed wetlands are showing great potential for water treatment in a variety of settings. They consist of a sealed shallow pit, pea gravel, and emergent aquatic plants such as cattail and bulrush. The gravel provides approximately a thousandfold increase in surface area for the growth of bacterial biofilms, which increase the rate of contaminant degradation or removal. Within the gravel matrix are distinct aerobic and anaerobic zones where specific microbial processes occur.

Constituents Targeted

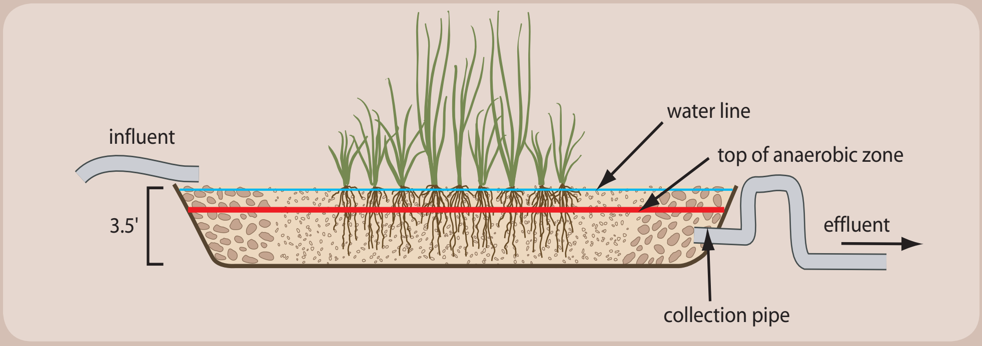
SSF wetlands are highly effective at removing nitrogen, phosphorus, suspended solids, biochemical oxygen demand (BOD), heavy metals, and pathogenic microorganisms. The degree of constituent removal depends on the loading rate, residence time, and available carbon to drive the microbial processes. Nitrogen is removed through microbial denitrification which converts nitrate to nitrogen gas. Phosphorus is taken up by plants and bacteria for metabolic purposes and also precipitates as calcium phosphate on the gravel. Heavy metals either adsorb to the biofilm or form insoluble metal sulfides. The pathogenic organisms adsorb to the biofilm and are inactivated by the bacterial enzymes, viruses, or plant secretions, or are eaten by grazing protozoans.

Nitrogen removal from secondary and primary effluent averages 85 to 99 percent for a four- to eight-day residence time. In waters with high ammonia levels, bulrush are very effective in facilitating the conversion to nitrate followed by anaerobic denitrification. Similar removal efficiencies are achieved for heavy metals in the low ppm-ppb range. Indicator bacteria such as total coliform, fecal coliform, and human/bacterial viruses can experience a 99.0 to 99.9 percent reduction. (Gersberg et al., 1986, 1987; Green et al., 1997).

The Orange County Water District (OCWD) tested SSF wetlands for treatment of dairy washwater and of surface waters under high-flow conditions.

Dairy Washwater Treatment

Current management practices for dairy washwater involve long-term storage in ponds where it is left to evaporate, percolate into groundwater, or is sprayed onto crops or disposal lands. To find out if SSF constructed wetlands could reduce the impacts from dairy waste on the groundwater basin in Chino, California, OCWD developed and constructed a dairy washwater treatment demonstration project in 2000. The wetlands treatment system was expected to maximize storage in existing ponds by reducing sediment loading in the washwater ponds through on-site treatment, increase pond capacity, and decrease the need to clean and scrape storage ponds.



Schematic cross-section of an SSF constructed wetland.

The project design included two SSF constructed wetlands (each 100 feet long by 70 feet wide by 3 feet deep) operating in parallel, and a facultative pond (30 feet square by 15 feet deep) for central collection of washwater prior to treatment. The combined size of both wetlands was 14,000 square feet, around one-third of an acre.

Photo: Stephen Lyon

SSF wetland designed to treat dairy washwater in Chino, CA. This front-loading wetland contains 10 percent coarse gravel, 10 percent aquatic grasses to remove solids and 80 percent bulrush to remove nutrients.

Raw washwater was first pumped from the existing dairy washwater lagoon into the facultative pond. This pond was designed to lower biochemical oxygen demand (BOD) by facilitating breakdown of complex organic material and particulate matter in the aerobic and anaerobic zones. The wind- and solar-driven aeration system in the facultative pond helped convert the ammonium ions to nitrate, circulate the water in the pond, and separate the deeper, turbid, anaerobic water from the clearer aerobic water in the upper three feet. The clearer water was then transported by gravity flow into the constructed wetlands.

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The two constructed wetlands utilized a horizontal subsurface-flow system where dairy washwater passed beneath the surface of a basin filled with ¾-inch pea gravel and planted with finely rooted grasses and bulrushes. Coarse, 1.5-inch gravel at the entry point removed large particulate matter from the washwater; the grasses filtered out smaller particles. The deep-rooted bulrush transported oxygen to the anaerobic zone, allowing for the nitrification of ammonium and subsequent denitrification of the nitrate in the washwater.

One wetland system had a front-loading design, where the washwater entered through multiple inlets along the short axis onto coarse gravel, grasses, and bulrushes, and drained into the collection box at the end of the basin. The other system was a side-loading basin, where washwater entered through multiple inlets along the longer sides of the wetland, passed through a narrow gravel bed, grasses, and bulrushes, and was collected through a perforated pipe along the center of the wetlands, which drained to the collection box.

Water quality samples and flow data were collected weekly for eleven months. Dairy washwater is approximately three to five times higher in major constituents (nitrogen, phosphorus, BOD) than domestic raw wastewater. The greatest success in treatment was for BOD, suspended solids, filtered and unfiltered chemical oxygen demand (COD), and coliforms. Removal of nitrogen and phosphorus was moderately successful. Total Kjeldahl nitrogen levels in raw washwater were 150-250 mg/L with ammonium levels of 100-200 mg/L; they were reduced 25 percent and 16 percent through wetlands treatment, respectively. BOD ranged from 50-350 mg/L, and steadily increased as the weather warmed, but reductions through wetlands treatment remained constant with an 85 percent average decrease. The concentration of suspended solids ranged widely (100-1,100 mg/L) in the raw water, but levels in wetlands effluent were consistently lower, with an average drop of 91 percent. Orthophosphate decreased 33 percent. The pH remained near neutral (7 to 8) throughout the system. Total and fecal coliform bacteria decreased 99 and 99.9 percent, respectively.

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The average flow rate through the wetlands was four gallons per minute with a residence time of approximately seven days. During spring, summer, and fall, the wetlands treated 66 percent of the farmer's washwater and removed approximately 1,300 pounds of nitrogen and 9,200 pounds of solids per year.

A longer residence time and more effective removal of inorganic solids from the raw water could have improved this system. Unlike domestic wastewater, the dairy washwater contained a significant fraction of clay that was washed off the cows prior to milking; it could eventually clog the wetland. Gersberg et al. (1989) found that a SSF wetland treated primary and secondary effluent—with lower inorganic solids content than dairy washwater—for eight years with no signs of clogging.

Design for High-Flow Surface Water

A study in Anaheim, California, tested the efficacy of SSF wetlands in treating surface water under high-flow conditions.

inflow rate (gallons/min)	average nitrate removal (%)	average phosphate removal (%)	application rate (inches/day)	residence time (days)	gallons/ acre/day
5 gpm	16.9	19.2	64.2	0.19	1,742,400
4 gpm	19.6	23.0	51.3	0.24	1,393,920
3 gpm	27.4	30.9	38.5	0.32	1,045,440
2 gpm	39.6	39.3	25.7	0.49	696,960
1 gpm	59.5	56.5	12.8	0.98	348,480
0.5 gpm	87.5	85.8	6.4	1.96	174,240

Treatment results from the high-flow surface water study in Anaheim shows percent nitrate and phosphate removal under various inflow rates and residence times.

Source water was taken from a percolation pond and well next to the Santa Ana River. This combination of surface runoff and tertiary effluent from the upper Santa Ana River watershed had a very low BOD, a significant aspect to the project, as the presence of a carbon source is crucial for nitrate removal.

The SSF wetland cells were three feet deep and rectangular, with the influent applied across the shorter axis. Adjacent to the OCWD Field Research Laboratory were six wetland cells (3.5 feet deep by 7.5 feet wide by 24 feet long) filled with ¾-inch pea gravel and planted with a monoculture of bulrushes, whose deep root system transported oxygen to the anaerobic zone to allow nitrification of the ammonium and subsequent denitrification of the nitrate. Micro-aerobic zones within the anaerobic region throughout the wetland facilitated removal, oxidation, and reduction of contaminants, including nutrients, organics, metals, and pathogens.

The loading or application rate (the volume added to the wetland per day, measured as height) ranged from 6.4 to 64 inches per day (0.5-5 gal/min). The bulrush plants were allowed to mature for one year and weekly samples of the influent and effluent were taken from June to October 1994. Results of the study are shown in the table above. Average inflow concentrations were 3.73 mg/L for nitrate and 1.78 mg/L for phosphate.

SSF Advantages

With their short residence times and high removal efficiencies, SSF wetlands have great potential for water treatment, offering several advantages over free-surface wetlands. SSF wetlands require less land area, reduce or eliminate vector (mosquito) problems, and operate year-round. Once constructed, SSF wetlands need relatively little maintenance. Flow rates should be checked weekly and plants cut down to ground level annually prior to the spring growth cycle. Water in the wetland moves as a function of positive displacement, so if there is no inflow, the subsurface water level is maintained except for evapotranspiration losses. In addition, having the water level below the surface helps to control odor and minimizes avian nutrient loading and the need to apply biocides. Because SSF wetlands are constructed, the physical/chemical/biological processes that occur within them can be easily controlled without having to deal with endangered species habitats or other permitting aspects. Ultimately, longer residence times and optimization of microbial processes yield the best effluent quality.

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