Ten Years of BNR Operating Experience For a Trickling Filter-Activated Sludge Combination

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Abstract This paper expands on previous studies undertaken at the Salmon Arm Water Pollution Control Centre, which was converted in 1986 from an activated sludge process with chemical phosphorus removal to a combined trickling filter-activated sludge biological nutrient removal process. The process change replaced air blowers with cascade aeration and reduced power requirements by nearly 50%. Ongoing efforts have been undertaken over the past ten years of operation to meet operational challenges and to optimize process performance. Over the most recent two years of operation described here, the effluent average orthophosphate concentration was 0.09 mg P/L, and the effluent average total P concentration was 0.5 mg P/L. The plant is not designed for full nitrification; however, process ammonia removal increased from 50% to 64% following the installation of higher density trickling filter media in 1998, and increased again to 75% following an increase in media irrigation rate in 2003.

Keywords activated sludge, biological nutrient removal, fixed growth, FGR-SGR, nitrification, phosphorus removal, trickling filter, wastewater treatment.

Introduction

Current technologies for biological nutrient removal (BNR) are normally based on variants of the diffused air activated sludge process, where all of the process bacteria are cultured in suspension in the process mixed liquor; in these systems, both nitrification and bacterial storage of phosphorus occur in a single aerated process step. However, the aerated retention time required for phosphorus uptake may differ from that required for nitrification, and it may therefore be difficult to optimize the size of the aerated component for both of the two biochemical processes simultaneously. In addition, the relatively long solids retention times needed for nitrification may produce a biomass with relatively poor settling qualities, which in turn requires larger final clarifiers.

The Water Pollution Control Centre (WPCC) at Salmon Arm, B.C. Canada was converted in 1986 from an air activated sludge process with chemical phosphorus removal to a BNR process that incorporated trickling filters as a component of the mainstream process flow. The process was identified as a fixed growth reactor-suspended growth reactor (FGR-SGR) combination. The two primary functions of the trickling filters (FGRs) were to provide low-energy cascade aeration of the process mixed liquor, and to add a fixed growth bacterial component to the process. Installation of the trickling filters increased the WPCC capacity from a service population of 6,000 to 8,500 people, and at the same time allowed decommissioning of two 56 kW duty aeration blowers, which were replaced by four 15 kW trickling filter irrigation pumps, resulting in a 47% reduction in installed aeration capacity for the biological treatment process (a third standby blower was retained for aeration of a nearby storage lagoon). The reduction in energy demand reflects the lower energy requirements for pumping (cascade aeration) versus blower aeration. The use of the trickling filters also resulted in an estimated 25% reduction in area requirement for the WPCC upgrade than would have been the case for an equivalent diffused air activated sludge process.

The addition of the trickling filters to the mainstream process provides an environment for fixed growth organisms that is not dependent on the solids retention time in the suspended growth component of the process. This separation of bacterial communities is designed to allow the suspended growth component to be optimized for biological phosphorus removal, with the fixed growth component being designed to accomplish the desired amount of nitrification. In controlled pilot-scale studies of the FGR-SGR process, 65% to 70% of the total process nitrification was attributed to the fixed growth (trickling filter) component (Gibb, 1995).

The WPCC effluent permit specifies a maximum total phosphorus concentration in the discharge of 1.0 mg P/L. The discharge permit does not specify restrictions on ammonia or other forms of nitrogen, and consequently the plant is not designed to accomplish full nitrification, nor is operation optimized for nitrogen removal. However, the plant is designed to accomplish sufficient ammonia removal to protect aquatic life, and undiluted samples of the plant effluent are routinely found to be non-acutely toxic according to the 96-hour LC_{50} rainbow trout bioassay.

Methods

Development and optimization of the FGR-SGR process at pilot scale and full scale has been ongoing since 1987 (e.g., Gibb et al. 1989, 1994 and 1998, Kelly 1987, and Kelly et al. 1995). The FGR-SGR process at Salmon Arm has relied since its inception on the activated primary concept as described by Barnard (1984) for provision of the simple carbon substrates needed to promote biological phosphorus removal. An autothermal thermophilic aerobic digester (ATAD) is used to stabilize and pasteurize the waste primary and secondary sludge solids. Chu et al. (1994) showed that the ATAD could be used to provide additional simple carbon substrates, but this has not been necessary to date.

A schematic of the FGR-SGR process as it was first constructed at Salmon Arm in 1986 is shown on Figure 1. At that time, the trickling filter media consisted of red cedar wood pallets with a specific surface area of approximately 26 m^2/m^3. The first generation design relied on endogenous denitrification of the return biological sludge stream to prevent nitrates from entering the anaerobic reactor (Figure 1). From 1992 through 1996, the solids contact tank was operated without aeration to promote denitrification. However, it was subsequently found that maintaining a residual nitrate concentration of at least 2 mg N/L in the process effluent enhanced biological phosphorus removal by suppressing secondary phosphorus release in the final clarifier. An aspirating surface aerator (Turborator™) with automated dissolved oxygen (DO) control was added to the solids contact tank in July of 1996, to improve control of nitrates in the process effluent (Gibb et al., 1998).

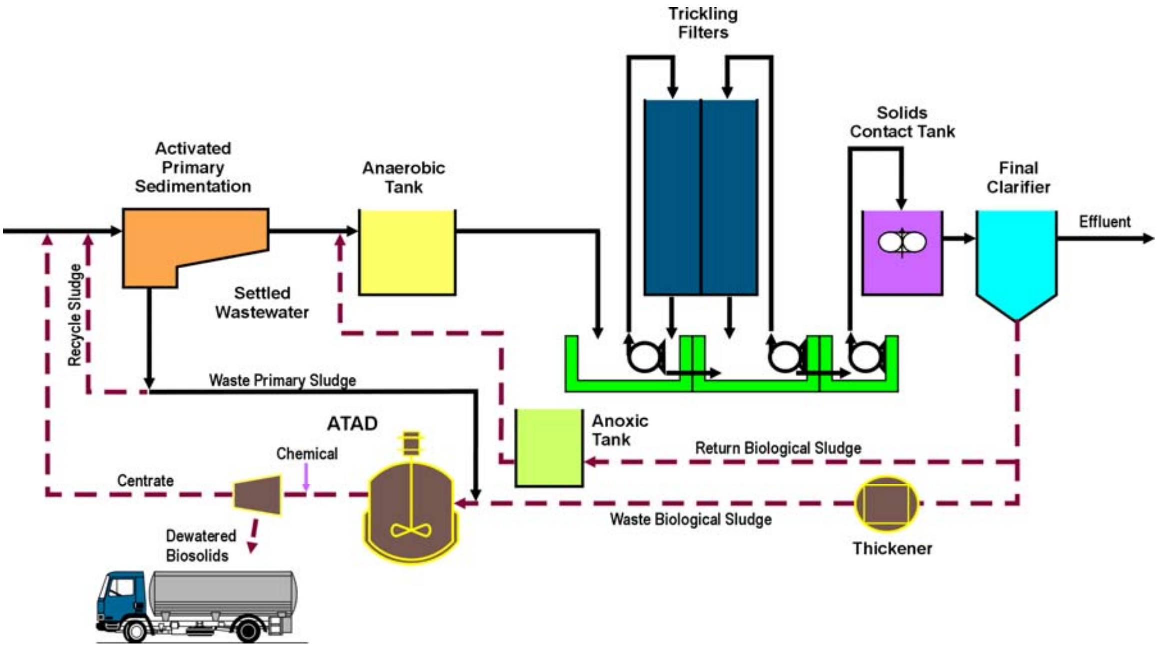

Figure 1 Salmon Arm WPCC FGR-SGR Process Schematic before 1997/98 Upgrade

A plant expansion and upgrade was undertaken during 1997/98 to address evolving regulatory requirements and increasing plant loads. At that time, the red cedar trickling filter media was replaced with 60^o cross flow PVC media (specific surface approximately 90 m^2/m^3) in response to concerns that the wooden media was deteriorating. At the same time, the suspended growth component of the FGR-SGR process was modified to reduce the risk of nitrates entering the anaerobic reactor. The process schematic of the FGR-SGR process following the 1997/98 upgrade is shown on Figure 2; the WPCC has operated in this configuration since 1998. The process operated with a single final clarifier until 2004, when a second final clarifier was added.

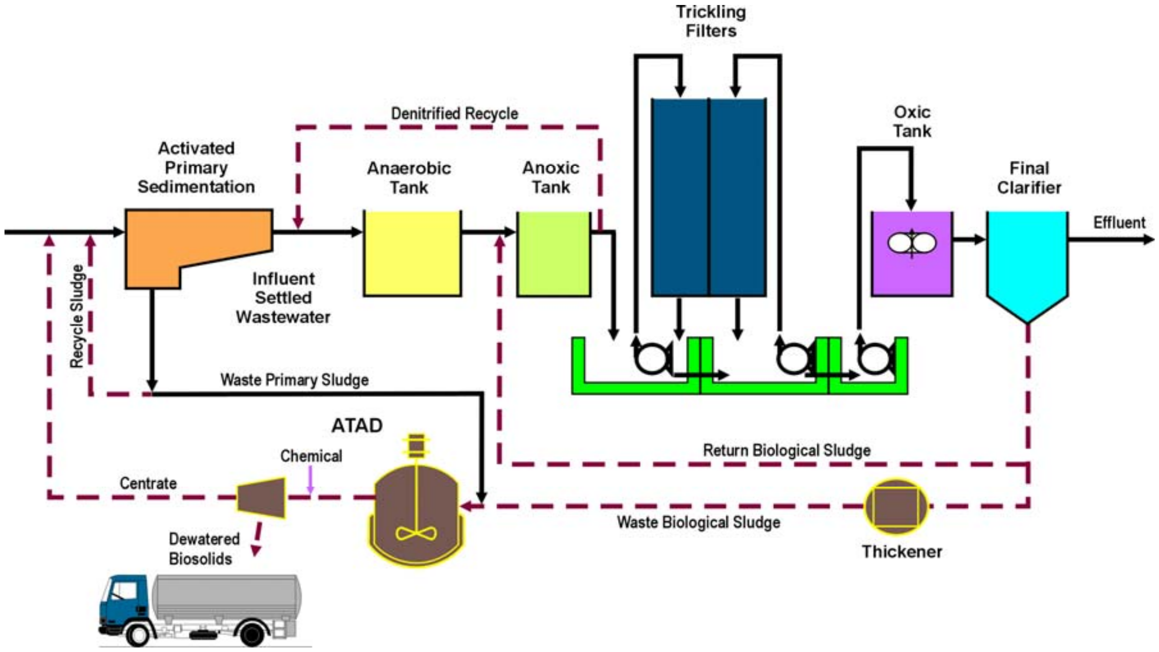

Figure 2 Salmon Arm WPCC FGR-SGR Process Schematic after 1997/98 Upgrade

Waste biological sludge from the liquid treatment process is stabilized in the ATAD along with the waste primary sludge; the digested biosolids are then dewatered in a centrifuge and used to manufacture topsoil. The centrate is discharged to the primary sedimentation tanks. Polymer and ferrous chloride are injected into the stream of digested sludge upstream of the centrifuge (Figures 1 and 2). The inclusion of the ferrous chloride (initiated in December 1999) has been found to reduce polymer use for dewatering by up to 50% (Kelly et al., 2000). Ferrous chloride added to the digested sludge stream also reacts with soluble phosphorus released in the ATAD, and helps to reduce phosphorus return to the biological process via the centrate stream.

The results presented in this paper were based on routine plant monitoring data obtained by operations personnel. Samples of the plant effluent were collected from the final clarifier overflow weir using an automated 24-hour composite sampler. Process influent ammonia concentration was assessed by grab samples taken at the discharge of the primary sedimentation tanks. All laboratory analyses were undertaken in accordance with APHA et al. (1992).

Results and Discussion

Phosphorus Removal

The WPCC effluent orthophosphate (ortho-P) concentration from July 1996 through July 2005 is shown on Figure 3 (plant influent total phosphorus concentration is not routinely monitored, but has been found in previous studies to be typically in the range 7 mg P/L to 8 mg P/L). Major process upgrades and operational changes over the past 10 years are noted on Figure 3. As shown, the addition of the aerator and automated DO control in the solids contact tank in July 1996 resulted in a significant improvement in phosphorus removal. Effluent ortho-P concentrations from July 1966 until construction of the plant upgrade began in the autumn of 1997 were less than 0.2 mg P/L (average 0.1 mg P/L).

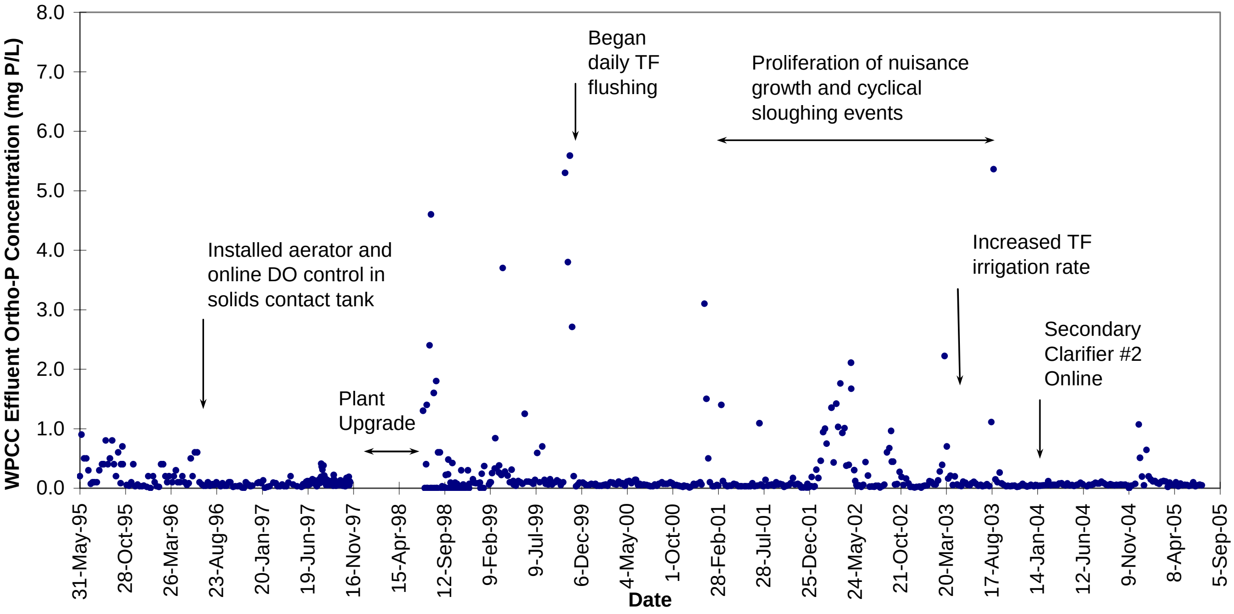

Figure 3 Summary of WPCC Effluent Ortho-P Concentration July 1996 to July 2005

The optimum operating mixed liquor suspend solids (MLSS) concentration for biological phosphorus removal based on experience prior to the 1997/98 plant upgrade was in the range 3,000 mg/L to 4,000 mg/L. Soon after the 1997/98 plant upgrade and installation of the cross flow media was completed, wide fluctuations from 500 mg/L to 8,000 mg/L in the SGR mixed liquor suspended solids (MLSS) concentration were observed. This was attributed to a gradual accumulation of process solids within the trickling filters, with subsequent large sloughing events. As shown on Figure 3, the cyclic solids accumulation and sloughing events had a detrimental impact on process phosphorus removal from July 1998 to November 1999. The sloughing events also caused excessive solids loading the final clarifier, resulting in occasional high effluent suspended solids concentrations.

In November of 1999, a daily flushing regimen was initiated, by increasing the normal trickling filter irrigation rate of 0.65 L/s/m^2 to 1 L/s/m^2 for about one hour each day. This reduced the fluctuations in process MLSS concentration, with a corresponding return to effective biological phosphorus removal (Figure 3). During the following two years of operation from late November 1999 through early January 2001, the WPCC effluent average ortho-P concentration was 0.06 mg P/L (maximum recorded value 0.14 mg P/L). The effluent average total P concentration during the same period was 0.7 mg P/L; however, although the severity of the periodic sloughing events was reduced, difficulties in controlling the process solids inventory still led to occasional high solids loading to the final clarifier during sloughing events, which in turn caused the effluent suspended solids and total P concentrations to exceed allowable values.

The periodic solids accumulation on the trickling filter media was attributed in part to the proliferation of a nuisance organism that developed on the trickling filter media. The growth coated the media with a glutinous white slime layer that appeared to be resistant to normal erosion by hydraulic shear forces (see photograph Figure 4). The responsible organism appears to be a stalked ciliate that has been tentatively identified as *Opercularia*. The nuisance growth subsequently spread to the aerobic process components downstream of the trickling filters (aeration tanks and final clarifier). Various strategies were developed to discourage the nuisance growth, including different media flushing regimes and shock loading of sodium hypochlorite to the biological process. In addition, operational strategies aimed at preparing for and managing the sloughing events were developed and tested. These strategies did not prove wholly effective, and there followed a period of poor plant performance from early 2002 until the summer of 2003 (Figure 3).

Figure 4 Photograph of Nuisance Slime Growth on Trickling Filter Media

In May of 2003, the cyclic flushing regimen was discontinued, and the steady-state trickling filter irrigation rate was increased to the former flushing rate of 1 L/s/m^2. Although the nuisance growth remained, the increase in trickling filter irrigation rate resulted in an immediate improvement in process biological phosphorus removal (Figure 3). A second final clarifier was commissioned in January 2004; this increased the clarifier floor area from 180 m^2 to 360 m^2, which improved operational control of the process solids inventory. Fluctuations in process MLSS concentration were still observed, but the magnitude and impact of the sloughing events was greatly reduced, and process phosphorus removal returned to normal (Figure 3).

Figures 4 and 5 show the frequency plots of plant effluent ortho-P and total P concentration from September 2003 (when the trickling filter irrigation rate was increased) through July 2005. As shown on Figure 4, the effluent average ortho-P concentration for that period was 0.09 mg P/L, with 97% of the recorded values less than 0.5 mg P/L. The effluent average total P concentration over the same period was 0.5 mg P/L, with 97% of the recorded values less than 1.0 mg P/L (Figure 5). The cause of the brief process upset that led to the three observed total P values in excess of 1.0 mg P/L in December of 2004 (see Figure 3) has not been determined.

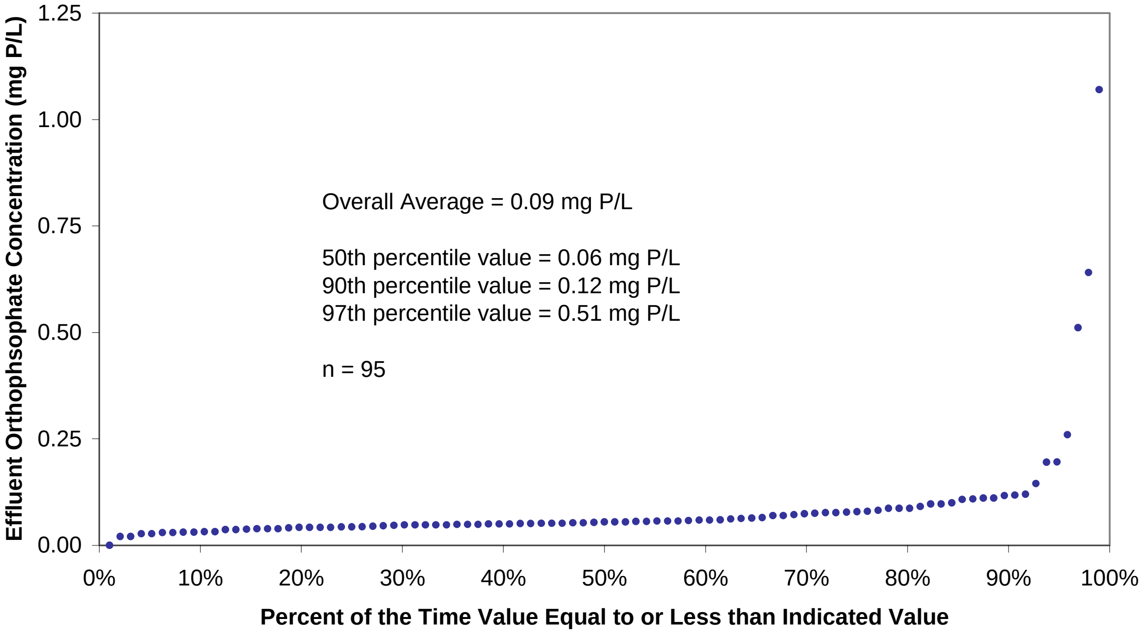

Figure 4 Frequency Plot of WPCC Effluent Ortho-P Concentration Sept/03 to Jul/05

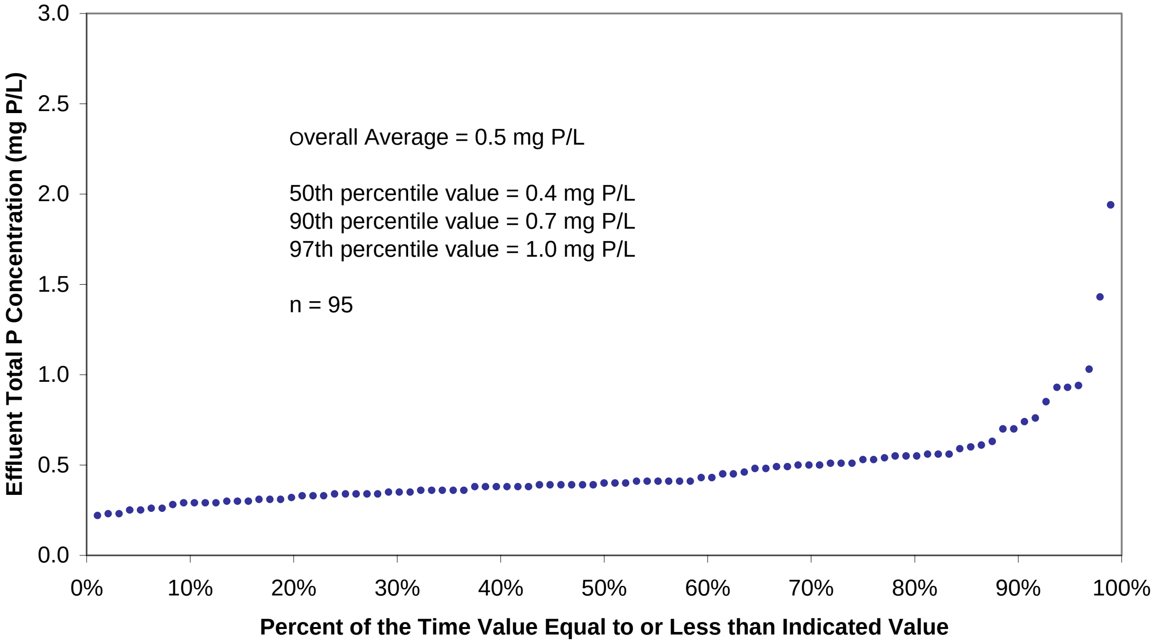

Figure 5 Frequency Plot of WPCC Effluent Total P Concentration Sept/03 to Jul/05

Nitrogen Removal

As stated earlier, nitrogen removal is not a requirement for the Salmon Arm WPCC. However, ammonia removal is undertaken to a level sufficient to ensure that the effluent is not found to be acutely toxic according to the 96 hour LC_{50} fish bioassay, and management of process nitrate concentrations is undertaken to optimize biological phosphorus removal. Process ammonia removal and effluent nitrate concentrations from July 1996 to July 2005 are summarized in Table 1.

Table 1 Summary of WPCC Ammonia Removal and Effluent Nitrate Concentration July 1996 to July 2005

Parameter	**Operating Period**		
	Jul 5/96 to Oct 30/97 **Cedar Pallet Media**	**July 3/98 to Sept 3/03** **X-Flow Media, IR = 0.6 L/s/m^2**	**Sept 4/03 to Jul 7/05** **X-Flow Media, IR = 1.0 L/s/m^2**
Average Daily Flow	4,240 m^3/day	4,425 m^3/day	4,865 m^3/day
Average Ammonia Concentration			
• Process Influent	25.3 mg N/L	31.4 mg N/L	32.5 mg N/L
• Process Effluent	11.9 mg N/L	10.6 mg N/L	8.3 mg N/L
• Percent Removal	50%	64%	75%
Effluent Average Nitrate + Nitrite Concentration	2.5 mg N/L	4.0 mg N/L	6.9 mg N/L

As shown in Table 1, there was an apparent improvement in ammonia removal from 50% to 64% following the installation of the higher density cross flow media during the summer of 1998, and effluent average ammonia concentration decreased slightly from 11.9 mg N/L to 10.6 mg N/L, despite a 30% increase in ammonia loading. At the same time, the effluent average NO_x (nitrate + nitrite) concentration increased from 2.5 mg N/L to 4.0 mg N/L. After the trickling filter irrigation rate (IR) was increased from 0.6 L/s/m^2 to 1.0 L/s/m^2 in September 2003, ammonia removal further improved to 75%, and the effluent average ammonia concentration decreased to 8.3 mg N/L, despite a further increase of 14% in process ammonia loading. The effluent average NO_x concentration increased from 4 mg N/L to 6.9 mg N/L following the increase in trickling filter irrigation rate. It should be noted that the volume of the solids contact/aeration tank was increased from 110 m^3 to 330 m^3 during the 1998 upgrade, and this may have contributed to improved process ammonia removal.

Sludge Settling

The settling qualities of the biological solids produced at the Salmon Arm WPCC have been consistently excellent, regardless of the process upsets described above. The sludge volume index (SVI) of the process biological solids was consistently less than 80 mL/g throughout the ten year period of record described here. Occasional high suspended solids in the plant effluent were generally caused by excessive solids loading to the final clarifier, and not by the settling qualities of the solids.

Conclusions

1. The combined trickling-filter activated sludge BNR process at Salmon Arm has achieved effective biological phosphorus removal equal to an equivalent air activated sludge BNR system over more than ten years of operation.
2. Cascade aeration of the mixed liquor in the combined trickling filter-activated sludge system has allowed a significant reduction in energy requirements compared to diffused air activated sludge.
3. The primary operational challenge associated with the combined trickling filter-activated sludge system has proven to be management and control of the process solids inventory. The process would benefit from additional study in this regard (note: a pilot-scale investigation of alternative media configurations is currently underway).
4. The combined trickling filter-activated sludge system is capable of effective nitrification. Pilot scale studies have shown that the combined process can be designed to accomplish the majority of nitrification within the trickling filters.
5. The biological solids produced in the combined trickling filter-activated sludge system consistently have excellent settling qualities.

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