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How Low Is Too Low?

Several years of low-dissolved-oxygen operations improve effluent quality

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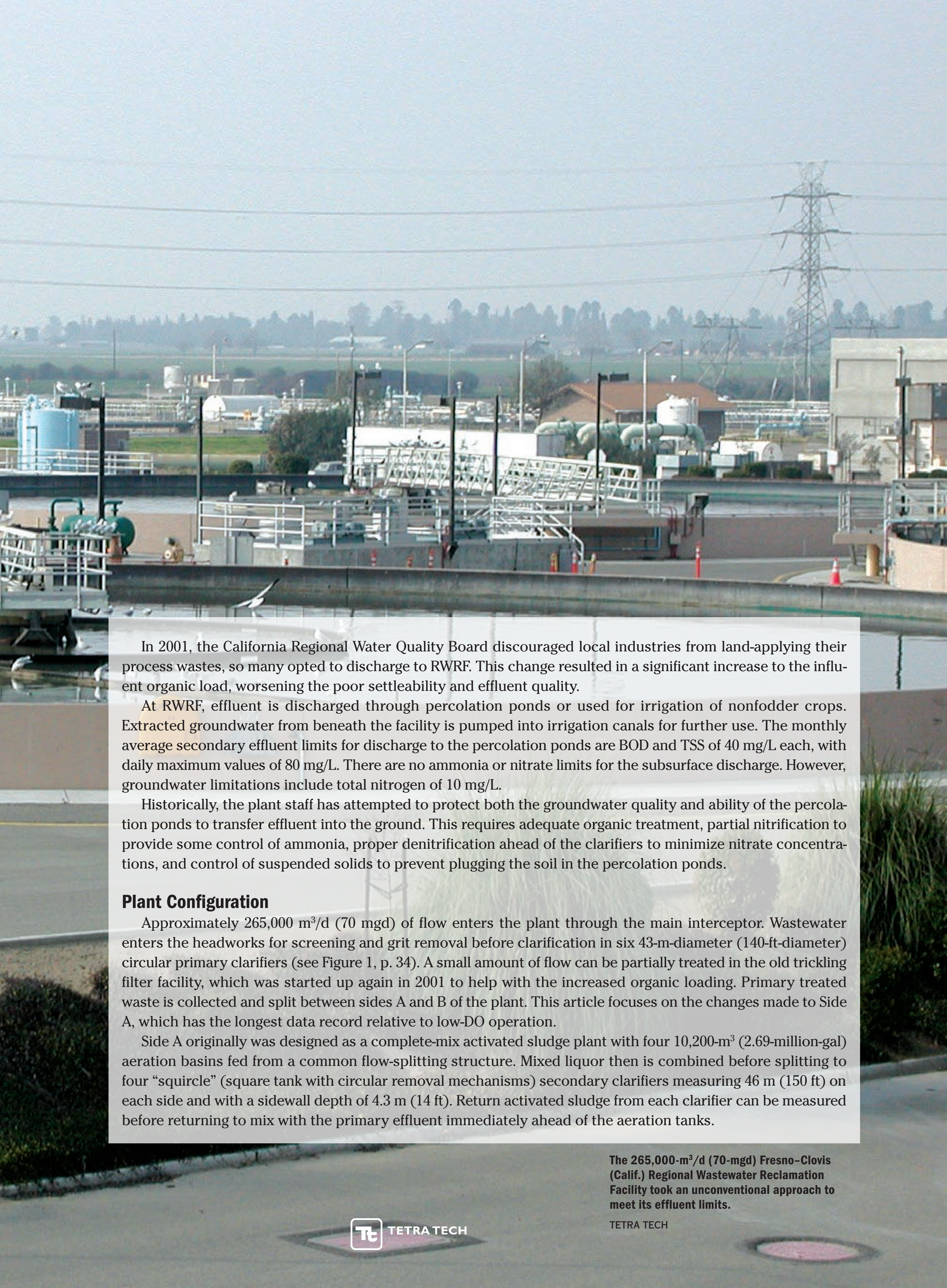
After taking on additional organic waste from local industries, the Fresno–Clovis Regional Wastewater Reclamation Facility (RWRF; Fresno, Calif.) found it difficult to meet requirements for effluent total suspended solids (TSS) and biochemical oxygen demand (BOD). Attempts to minimize nitrification and subsequent clarifier denitrification exacerbated settling problems. The plant operations staff embarked on a radical approach: Use a low dissolved-oxygen (DO) concentration in the aeration tanks. Data show that, even though hydraulic and organic loads increased, low-DO operation has been successful in improving both settleability and effluent quality for the last several years.

Plant Conditions

Located in California's Central Valley, RWRF treats the wastewater from the cities of Fresno and Clovis. This wastewater contains a significant amount of highly concentrated, quickly metabolized waste from the red-meat, wine, and fruit-processing industries. Since the waste entering the treatment plant has high temperatures that promote high biomass metabolic rates, septicity prevails. Major operational problems included poor activated sludge settleability, high oxygen demand, and difficulties with denitrification in the secondary clarifiers.



In 2001, the California Regional Water Quality Board discouraged local industries from land-applying their process wastes, so many opted to discharge to RWRF. This change resulted in a significant increase to the influent organic load, worsening the poor settleability and effluent quality.

At RWRF, effluent is discharged through percolation ponds or used for irrigation of nonfodder crops. Extracted groundwater from beneath the facility is pumped into irrigation canals for further use. The monthly average secondary effluent limits for discharge to the percolation ponds are BOD and TSS of 40 mg/L each, with daily maximum values of 80 mg/L. There are no ammonia or nitrate limits for the subsurface discharge. However, groundwater limitations include total nitrogen of 10 mg/L.

Historically, the plant staff has attempted to protect both the groundwater quality and ability of the percolation ponds to transfer effluent into the ground. This requires adequate organic treatment, partial nitrification to provide some control of ammonia, proper denitrification ahead of the clarifiers to minimize nitrate concentrations, and control of suspended solids to prevent plugging the soil in the percolation ponds.

Plant Configuration

Approximately 265,000 m^3/d (70 mgd) of flow enters the plant through the main interceptor. Wastewater enters the headworks for screening and grit removal before clarification in six 43-m-diameter (140-ft-diameter) circular primary clarifiers (see Figure 1, p. 34). A small amount of flow can be partially treated in the old trickling filter facility, which was started up again in 2001 to help with the increased organic loading. Primary treated waste is collected and split between sides A and B of the plant. This article focuses on the changes made to Side A, which has the longest data record relative to low-DO operation.

Side A originally was designed as a complete-mix activated sludge plant with four 10,200-m^3 (2.69-million-gal) aeration basins fed from a common flow-splitting structure. Mixed liquor then is combined before splitting to four "squircle" (square tank with circular removal mechanisms) secondary clarifiers measuring 46 m (150 ft) on each side and with a sidewall depth of 4.3 m (14 ft). Return activated sludge from each clarifier can be measured before returning to mix with the primary effluent immediately ahead of the aeration tanks.

The 265,000-m^3/d (70-mgd) Fresno–Clovis (Calif.) Regional Wastewater Reclamation Facility took an unconventional approach to meet its effluent limits.

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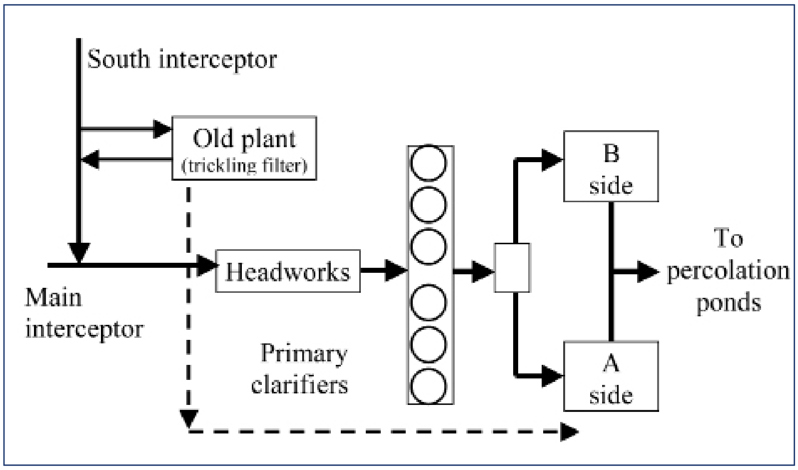
Figure 1. Fresno–Clovis Wastewater Treatment Plant



Data showed a low primary BOD removal efficiency of approximately 15%. Rising gas bubbles seemed to provide so much mixing that anticipated BOD removal was severely hindered. Therefore, staff reduced the number of active primary clarifiers from six to four. The reduced detention time and lower gas production increased BOD removal efficiencies to as much as 30%. As a result, organic loading to the aeration tanks was reduced significantly, enabling staff to begin loading Side A at a higher rate to protect the effluent quality from Side B. The hydraulic load remained high during October 2001, the first month of the low-DO project, but quickly was reduced. This drop was due to a combination of improved BOD removal in the primary clarifiers and reduced influent BOD at the end of the agricultural processing season.

The Fresno–Clovis system had problems with poor-settling sludge. It was common to have a meter or more of denitrified sludge floating on the surface of the secondary clarifiers. Operations staff attempted to minimize nitrification by reducing the mean cell residence time (MCRT) to less than 2 days. Reduced MCRT decreased both the degree of nitrification and the associated clarifier denitrification, and this approach worked well for several years.

However, by 2001, the combination of long sewer detention time, high temperatures, and soluble organics apparently produced an influent with high concentrations of organic acids. This caused significant problems in the primary clarifiers and with activated sludge settleability, even after two clarifiers had been taken off-line.

In the aeration tanks, the high organic loads and high temperatures provided an aerobic environment that enabled microorganisms to grow rapidly. This often caused increased turbidity, along with low-density flocs that tended to settle poorly. Data show that organic acid concentrations were as high as 122 mg/L, much higher than a more typical value of 25 mg/L. Data also suggest that the high seasonal temperature months, which also correspond to periods of high agricultural production, provide the greatest potential for sludge bulking due to septic-sulfide filamentous microorganisms. In the aeration tanks, the bacteria would use oxygen so quickly that DO was depressed to the range of 0.65 to 0.9 mg/L, causing growth of low-DO filamentous organisms. Further, it was difficult, if not impossible, to elevate DO higher than 1.0 mg/L due to the high organic load and nitrification. Therefore, a sludge volume index (SVI) of 300 to 600 mL/g was common.

Under these operating conditions, the

However, in July 2003, the staff began returning sludge from the secondary clarifiers to a point farther upstream, to the aeration tank influent channel that directs primary effluent to the aeration tanks. This channel, only lightly aerated, is intended to provide some degree of anaerobic selection and improved sludge settleability (see Figure 2, below).

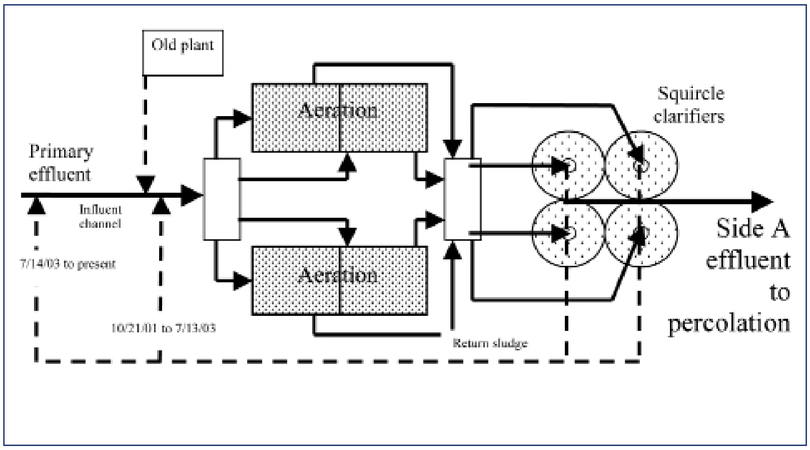
Side B is also an activated sludge system, but it has capability for partial step-feeding. Four aeration tanks are each divided into two passes, with five sections in the first pass and two sections in the final pass.

The original design capacity of Side A was 190,000 m^3/d (50 mgd), based on an influent BOD and TSS of 240 mg/L each. The plant was seriously overloaded organically when the low-DO modifications were implemented in late 2001. During a facility evaluation in 2003, Side A capacity was revised to 126,000 m^3/d (33.3 mgd), based on its high BOD loading.

Operational Changes

Prior to initiating the low-DO project in 2001, RWRF staff implemented operational changes to stabilize the activated sludge process. Paramount in this effort was modified primary clarifier operation.

Figure 2. Side A Process



process was easily upset and difficult to control. The clarifier denitrification problem was solved, but another problem — poor sludge settleability — was produced.

Process Control Approaches

In October 2001, RWRF implemented changes to improve process stability and minimize TSS discharge to the percolation ponds. The first step was to increase MCRT to slow microorganism growth. However, the staff knew that this would lead back to the old nitrification–denitrification problems that had plagued the system for years. Therefore, other methods had to be developed that would minimize clarifier denitrification.

For Side A, three different approaches were considered. Alternating on–off aeration could provide nitrification and denitrification in the same tank. However, staff was concerned that the old aeration grid was not capable of handling the stress. Another option was constructing a pumping system and curtain to provide an anoxic section with recycling. However, this option was deemed too time-consuming and expensive, and it would require taking the aeration tanks off-line when they were needed the most. Instead, RWRF staff decided to reduce DO to less than 0.5 mg/L. This change would provide simultaneous nitrification–denitrification while minimizing the proliferation of low-DO filaments.

Another objective was to give the organisms as much time as possible in an aeration tank to maximize stabilization of the biomass. Stabilized organisms with a low specific oxygen uptake rate would denitrify less in the clarifiers and also would minimize organic acid production that could promote growth of filamentous microorganisms. For the microorganisms to be at a completely endogenous respiration stage when they discharge from the aeration tank, a low return-sludge flow rate was maintained.

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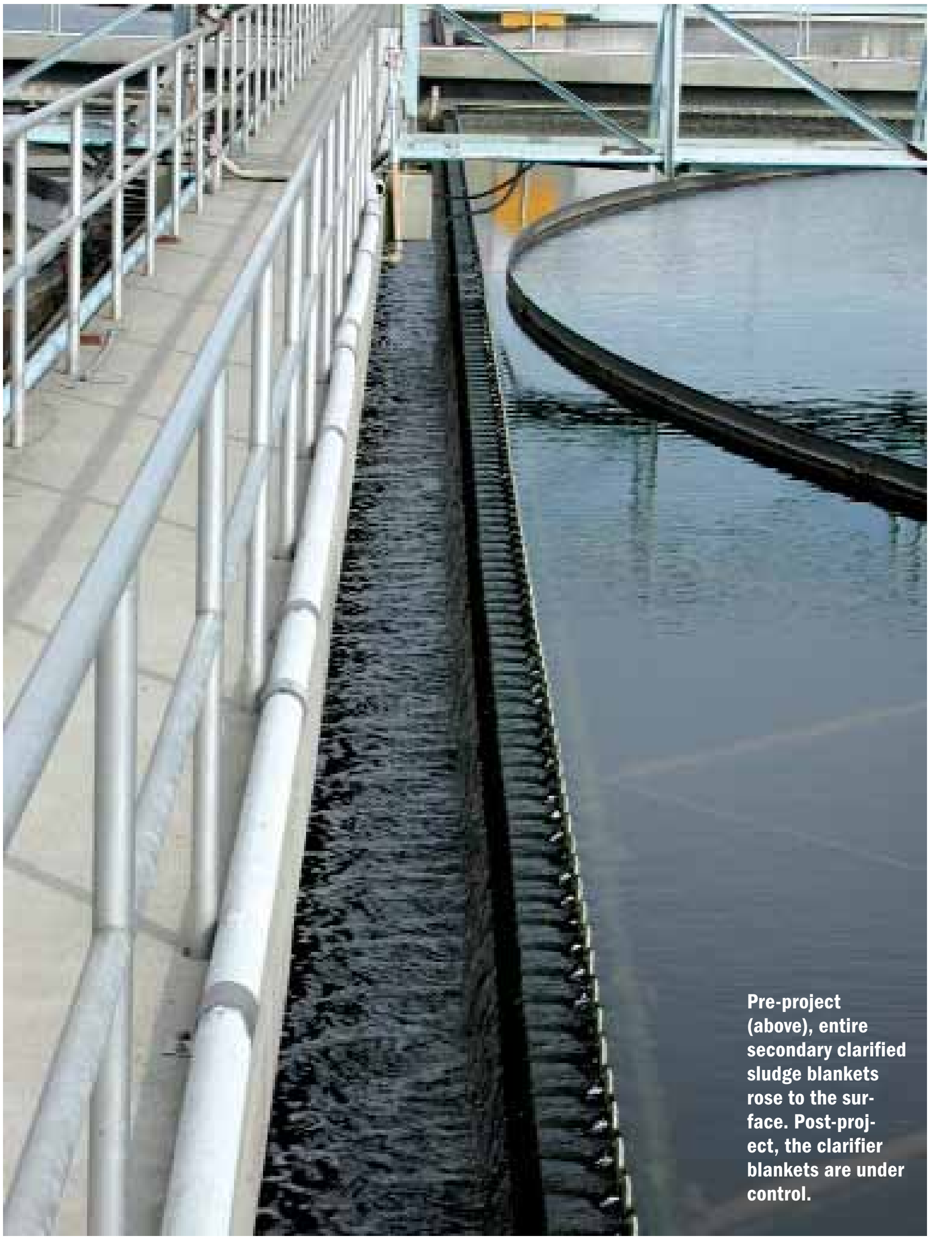

Pre-project (above), entire secondary clarified sludge blankets rose to the surface. Post-project, the clarifier blankets are under control.

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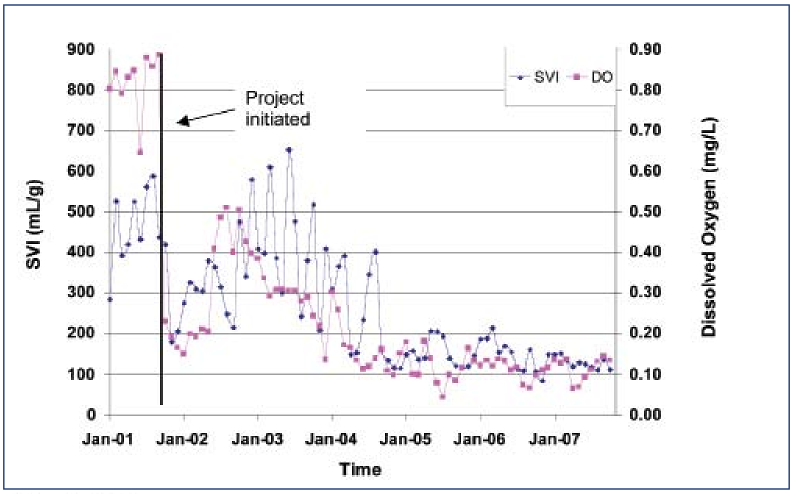
Wastewater Characteristics for Side A Showing Average/Peak Month Values

Parameter	Unit	2001	2002	2007
Flow	m^3/s (mgd)	1.30 (29.7) / 1.79 (40.9)	1.58 (36.1) / 1.77 (40.5)	1.55 (35.4) / 2.10 (48.0)
Influent BOD	kg/d (lb/d)	20,590 (45,394) / 42,842 (94,450)	25,615 (56,470) / 29,407 (64,831)	26,156 (57,663) / 42,842 (94,450)
MCRT	day	No data	4.54 / 6.98	4.72 / 5.08
MLSS	mg/L	1899 / 3487	1708 / 3069	2743 / 3362
Effluent BOD	mg/L	37 / 64	29 / 81	23.2 / 27.9
Effluent TSS	mg/L	42 / 158	27 / 87	15.2 / 21.7

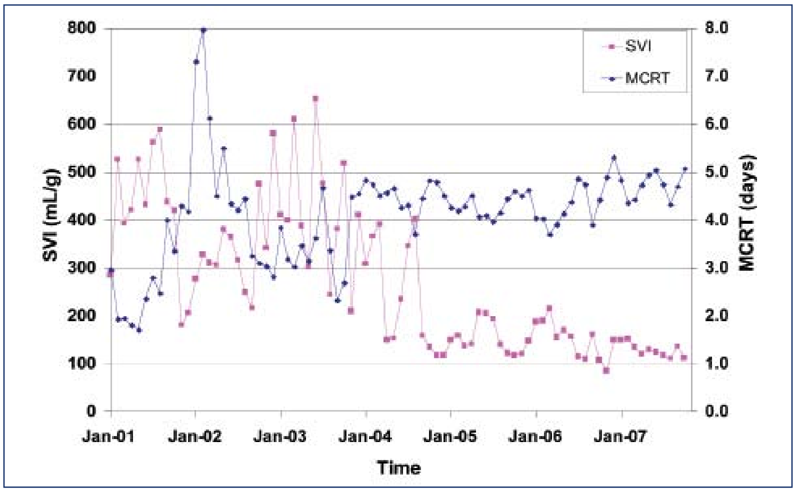
BOD = biochemical oxygen demand.
MCRT = mean cell residence time.
MLSS = mixed liquor suspended solids.
TSS = total suspended solids.

Figure 3. Improved Sludge Settleability With Low-DO Operation



DO = dissolved oxygen.
SVI = sludge volume index.

Figure 4. MCRT Effects on Sludge Settleability



MCRT = mean cell residence time.
SVI = sludge volume index.

Modification Challenges

Modified control on Side A began Oct. 2, 2001. From the start, it was difficult to maintain DO levels between 0.1 and 0.5 mg/L.

The membrane-type DO sensors in the aeration tanks were in continual need of recalibration and were not deemed reliable at very low DO concentrations. Switching to optical DO probes significantly improved the staff's ability to maintain the targeted DO.

In addition, RWRF had to decide how to take a representative DO reading. The aeration tanks are square, with dimensions of 76 m (250 ft) on each side. The most recent plant upgrade had converted the aeration system from sparger aeration to full-bottom-coverage, fine-bubble diffused aeration that did not provide complete mixing. There are some walkways to where the old sparger aerators had been located, but there were only four of these per tank, and none reached well into the tank. Therefore, it was determined that all DO readings would be taken at one spot in each tank: the end of the walkway closest to the effluent collection point. Thus, the operations staff did not know the actual DO value at points in the tank other than the "official" DO point. At the head of the tank, the DO could have been less than the recorded values — even 0.0 mg/L in certain areas. However, the operations staff had confidence that DO values much higher than those recorded would have been rare elsewhere in the system because of the high organic load.

Finally, some operators initially felt uncomfortable using such low DO values.

Therefore, the DO level was often higher than the desired low range, approaching 1.0 mg/L at times. During these periods, excessive nitrification and extensive filament growth occurred, causing poor settleability, clarifier denitrification, and high effluent suspended solids concentrations.

Results

Data show that even though the hydraulic and organics loads increased at RWRF, low-DO operation has been successful (see table, p. 36).

Settleability. During the first 9 months of 2001, the system DO typically was maintained at a concentration between 0.8 and 0.9 mg/L in an effort to control nitrification (see Figure 3, p. 36). When the low-DO operation began in October 2001, DO concentration was lowered to 0.5 mg/L immediately and down to 0.15 mg/L within 4 months. The sludge settleability quickly responded from its initial SVI values in the 300- to 600-mL/g range to values in the 200- to 380-mL/g range.

In June 2002, many staff thought it worthwhile to initiate higher DO levels and raised them to a 0.4- to 0.5-mg/L range for about 8 months. Since then, the trend has been to lower DO levels. The data suggest that maintaining DO as close to 0.1 mg/L as possible provides the best sludge settleability, even during times of high organic load from agricultural processing facilities and high temperatures.

At low DO levels, there seems to be a correlation between SVI and MCRT (see Figure 4, p. 36). In general, SVI responds favorably to somewhat longer MCRTs, up to approximately 5 days. By early 2004, the staff had determined that the best MCRT operational range was between 4 and 5 days. With an MCRT of approximately 4.5 days, SVI approached 100 mL/g. However, staff had experimented with an even longer MCRT in early 2002 and found that too much nitrification occurred for the available denitrification power at that time. As shown in Figure 4, high effluent TSS values occurred due to clarifier denitrification.

Effluent quality. Figure 5 (p. 39) presents effluent BOD, TSS, and ammonia data. Since the project's initiation, Fresno's significantly overloaded-plant discharge has been less than permit limits for BOD all but 8 months and for TSS all but 7 months. Total BOD is still used for effluent monitoring, and the high BOD levels are due to nitrogenous demand from partial nitrification. Therefore, staff implemented a maximum air-input rate limit to control nitrification and lessen clarifier denitrification further.

The major effect of the approach was on the

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Pre-project, the facility experienced denitrification problems in its secondary clarifiers (above), and diminished effluent quality. Post-project (left), the clarifier problems have been resolved, and high-quality effluent has been achieved.

effluent suspended solids concentration. There is still a significant SVI problem that has persisted for several years, but the system seems capable of performing satisfactorily in spite of high SVI. There were brief periods during the agricultural processing season in 2003 and 2004 when good settleability was lost due to the high organic loading. However, during the 2005 to 2007 period, no values exceeding the permit limits occurred.

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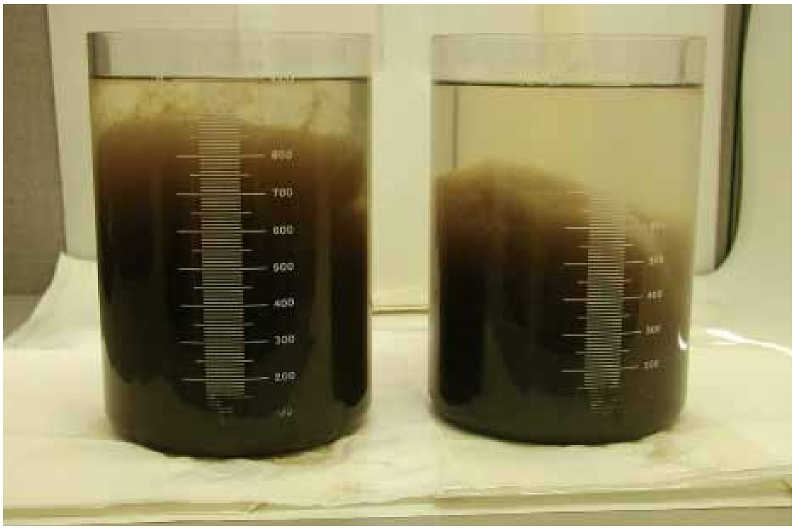

Pre-project, settleability was poor.

Energy use. Treatment capability is only one aspect of the low-DO operation. Another important aspect is the potential reduction in electrical energy required to operate the aerators. Data suggest that the low-DO approach had a sizeable effect on keeping aeration power use fairly constant while the plant BOD load increased more than 20% (see Figure 6, right). Based on calculating aerator oxygen-transfer efficiency, reducing the DO concentration from 2.0 mg/L to 0.2 mg/L should produce an increase in oxygen-transfer efficiency of approximately 29% at Fresno's elevation of approximately 91.4 m (300 ft). This means 29% less horsepower is required to satisfy the microorganisms' oxygen demand. It also could be argued that the low DO level would reduce the amount of nitrification, thus reducing the amount of oxygen

Post-project, this aeration tank is running at very low dissolved-oxygen concentrations.

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required to be transferred. This is a benefit that was not even considered at the beginning of the project, since the initial objective was to improve secondary effluent quality, rather than reduce operational costs. The potential savings were large enough that RWRF initiated low-DO operation on Side B in 2004. In addition to the reduction in energy use and the resulting savings in operational costs, the innovative approach also can lead to significant reduction in greenhouse gas releases.

Smooth Sailing

The modified approach took more operation, maintenance, and instrumentation staff time, but the results were positive. No new problems have surfaced as a result of the low-DO process except the requirement for additional operator attention to perform the necessary testing and instrument calibration and to initiate process-control actions.

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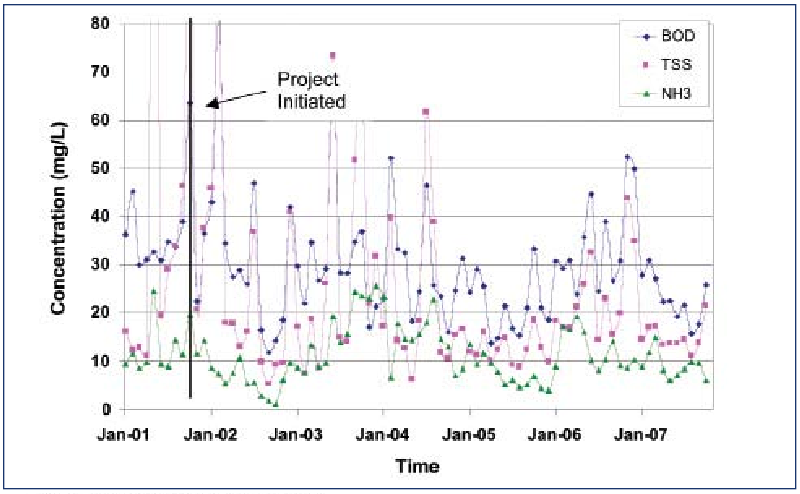
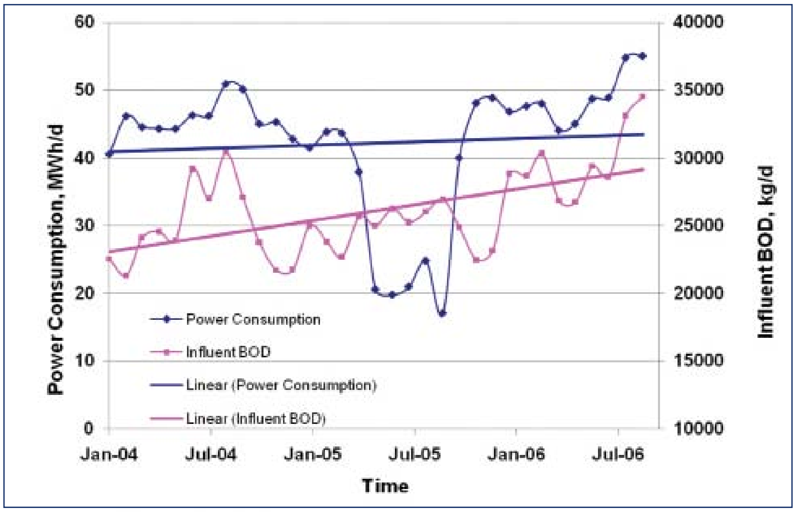
Figure 5. Effluent BOD, TSS, and Ammonia



BOD = biochemical oxygen demand.
TSS = total suspended solids.

Figure 6. Energy Usage Remained Relatively Constant While Influent BOD Load Increased Significantly



BOD = biochemical oxygen demand.

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