United States Environmental Protection Agency
Office of Water Washington, D.C.
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Wastewater Technology Fact Sheet
Trickling Filter Nitrification

DESCRIPTION

Nitrogen is one of the principal nutrients found in wastewater. Discharges containing nitrogen can severely damage a water resource and it's associated ecosystem. As a result, several chemical, physical and biological processes have been used to promote the removal of nitrogen. Nitrification and denitrification are two suggested processes that significantly reduce nitrogen levels in wastewater. This fact sheet will primarily focus on the nitrification process using a trickling filter system. TFs are designed as aerobic attached growth reactors and have been proven to be suitable for the removal of ammonia nitrogen.

Nitrogen Content in Wastewater

Nitrogen exists in many forms in the environment and can enter aquatic systems from either natural or human-generated sources. Some of the primary direct sources or transport mechanisms of nitrogen from sewage include:

- Untreated sewage—direct discharge.
- Publically owned treatment works (POTW) effluent—direct discharge, land application.
- POTW waste solids—direct discharge, land application.
- Septic tanks and leaching fields—groundwater movement.

Untreated sewage flowing into a municipal wastewater facility has total nitrogen concentrations ranging from 20 to 85 mg/L. The nitrogen in domestic sewage is approximately 60 percent ammonia nitrogen, 40 percent organic nitrogen, and small quantities of nitrates.

Treated domestic sewage has varying levels of nitrogen, depending on the method of treatment used. Most treatment plants decrease the level of total nitrogen via cell synthesis and solids removal. However, unless there is a specific treatment provision for nitrification, most ammonia nitrogen passes through the system and is discharged as part of the plant effluent.

The presence of ammonia-nitrogen in discharges from wastewater facilities can result in ammonia toxicity to aquatic life, additional oxygen demand on receiving waters, adverse public health effects, and decreased suitability for reuse.

Biological Nitrification

Nitrification is a process carried out by a series of bacterial populations that sequentially oxidize ammonium to nitrate with intermediate formation of nitrite carried out by *nitrosomonas* and *nitrobacter*. These organisms are considered autotrophic because they obtain energy from the oxidation of inorganic nitrogen compounds. The two steps in the nitrification process and their equations are as follows:

1) Ammonia is oxidized to nitrite (NO_2^-) by *Nitrosomonas* bacteria.

$$2\ NH_4^+ + 3\ O_2 \rightarrow 2\ NO_2^- + 4\ H^+ + 2\ H_2O$$

2) The nitrite is converted to nitrate (NO_3^-) by *Nitrobacter* bacteria.

$$2\ NO_2^- + O_2 \rightarrow 2\ NO_3^-$$

Once the nitrate is formed, the wastewater can either flow to a clarifier or continue on through a denitrification process to reduce the nitrate to nitrogen gas that is released into the atmosphere. The process is dependent on the desired percent of nitrification. Since complete nitrification is a sequential reaction treatment process, systems must be designed to provide an environment suitable for the growth of both groups of nitrifying bacteria. These two reactions essentially supply the energy needed by nitrifying bacteria for growth.

There are several major factors that influence the kinetics of nitrification. These are organic loading, hydraulic loading, temperature, pH, dissolved oxygen concentration, and filter media..

1. Organic loading: The efficiency of the nitrification process is affected by the organic loadings. Although the heterotrophic biomass is not essential for nitrifier attachment, the heterotrophs (organisms that use organic carbon for the formation of cell tissue) form biogrowth to which the nitrifiers adhere. The heterotrophic bacteria grow much faster than nitriifers at high BOD concentrations. As a result, the nitrifiers can be over grown by heterotrophic bacteria and eventually cause the nitrification process to cease. In order to achieve a high level of nitrification efficiency, the organic loadings listed in Table 1 should be maintained.

2. Hydraulic loading: Wastewater is normally introduced at the top of the attached growth reactor and trickles down through a medium. The value chosen for the minimum hydraulic loading should ensure complete media wetting under all influent conditions. Hydraulic and organic loading are not independent parameters because the wastewater concentration entering the plant cannot be controlled. The total hydraulic flow to the filter can be controlled to some extent by recirculation of the treated effluent. Recirculation also increases the instantaneous flow at points in the filter and reduces the resistance to mass transfer. This also increases the apparent substrate concentration and the growth and removal rate. The third major benefit of recirculation in nitrifying trickling filters is the reduction of the influent BOD concentration which makes the nitrifiers more competitive. This in turn increases the nitrification efficiency and increases the dissolved oxygen concentration.

TABLE 1 TYPICAL LOADING RATES FOR SINGLE-STAGE NITRIFICATION

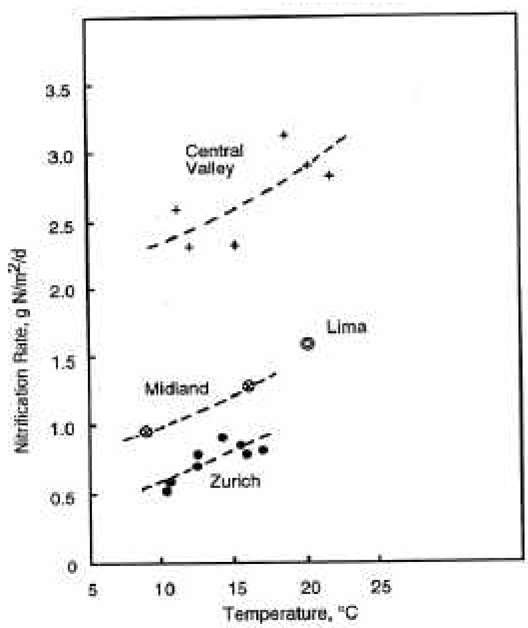
TF Media	% Nitrification	Loading Rate lb BOD/1,000 ft^3/d (g BOD/m^3/d)
Rock	75-85	10-6 (160-96)
	85-95	6-3 (96-48)
Plastic	75-85	181-12 (288-192)
Tower TF	85-95	12-6 (192-96)

Source : Metcalf & Eddy, Inc. with permission from The McGraw-Hill Companies, 1991.

3. Temperature: The nitrification process is very dependent on temperature and occurs over a range of approximately 4E to 45E C (39E to 113 E F). Quantifying the effects of temperature on the nitrification process has been very difficult and as a result the effects are variable. Higher nitrification rates are expected to be more affected by temperature than lower rates of nitrification. Figure 1 shows how temperature can effect nitrification rates in a TF system.

4. pH: According to EPA findings (EPA, 1993), pH levels in the more acidic range have been reported to decrease the rate of ammonium oxidation. As a result, nitrification rates may drop significantly as pH is lowered below neutral range. For

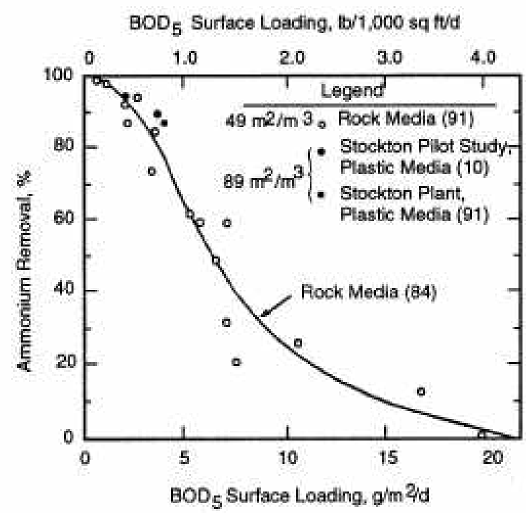
performance stability it is best to maintain a pH between 6.5 and 8.0. The effect of lower pH conditions, if anticipated, should not be ignored when sizing nitrification reactors, even though acclimation may decrease the effect of pH on the nitrification rate.



Source: Parker et al., 1990.

FIGURE 1 EFFECTS OF TEMPERATURE ON NITRIFICATION RATES IN TRICKLING FILTERS

5. Dissolved Oxygen (DO): The concentration of dissolved oxygen affects the rate of nitrifier growth and nitrification in biological waste treatment systems. The DO value at which nitrification is limited can be 0.5 to 2.5 mg/L in either suspended or attached growth systems under steady state conditions depending on the degree of mass-transport or diffusional resistance and the solids retention time. The maximum nitrifying growth rate is reached at a DO concentration of 2 to 2.5 mg/L. However, it is not necessary to grow at the maximum growth rate to get effective nitrification if there is adequate contact time in the system. As a result there is a broad range of DO values where DO becomes rate limiting. The DO value might be at 2.5 in a high rate activated sludge process because the bacteria have little time to accomplish nitrification while very effective nitrification can be achieved in an aeration ditch where the hydraulic retention time is 24 hours. A high solids retention time may be required to ensure complete nitrification at low DO concentrations and for conditions where diffusional resistance is significant. Under transient conditions of organic shock loading, diffusional resistance and heterotrophic/nitrifier competition can increase the limiting DO value significantly. As a result, nitrite conversion to nitrate can become the rate limiting step in the nitrification process. The intrinsic growth rate of *nitrosomonas* is not limited at DO concentrations above 1.0 mg/L, but DO concentrations greater than 2.0 mg/L may be required in practice. Figure 2 illustrates how the BOD_5 surface loading can influence the percent of ammonium removal.

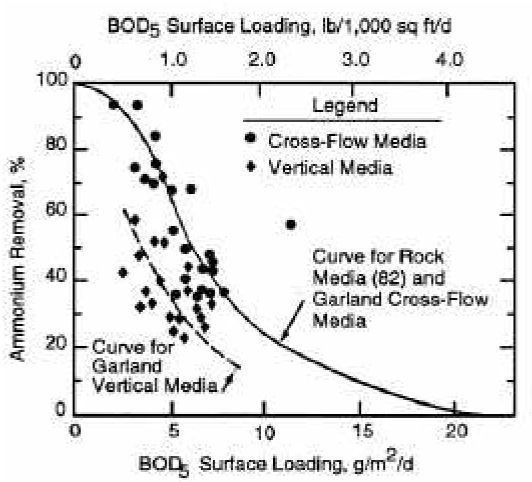


Source: Parker & Richards, 1986.

FIGURE 2 EFFECT OF BOD_5 SURFACE LOADING ON NITRIFICATION EFFICIENCY OF ROCK AND PLASTIC MEDIA TRICKLING FILTERS

6. Filter Media: The greater the surface area of plastic media, the greater the ability of the TF to accomplish nitrification at higher volumetric loadings relative to rock media

filters. Filter media provide more area for bacteria growth and therefore provide more bacteria "workmen." Plastic filter media also provide better gas transfer due to the greater draft and higher void fraction, and less plugging. One of the greatest benefits of plastic filter media is that they are light and can be constructed to greater depths. This increases the hydraulic load capacity and improves mass transfer. Rock filters, on the other hand, often have poor ventilation, particularly when water and air temperatures are similar or identical. Figure 3 evaluates how different filter media can affect the nitrification process.



Source: Parker & Richards, 1986.

FIGURE 3 PERFORMANCE COMPARISON OF VARIOUS TRICKLING FILTER MEDIA

APPLICABILITY

Stockton, California

A study done in Stockton, California evaluated the nitrification performance of plastic and rock media trickling filters. The results indicated that a 90% ammonium removal was achieved at a BOD_5 surface loading rate of ~2.5 g/m^2/day (0.51 lb/1000sq.ft./day) for both rock and plastic media trickling filters. This study also noted an increase in nitrification performance from 67 to 87 percent when the recirculation ratio was increased from 2.7 to 3.8. The air circulation was increased by operating more ventilation fans. Both of these actions increased the DO concentration in the bulk liquid, resulting in enhanced overall treatment performance. This study also looked at specific hydraulic patterns and retention times in plastic media trickling filters. The plastic media with cross-flow characteristics, when compared to vertical flow media, increase the hydraulic retention time between the biofilm and the influent and provide superior oxygen transfer.

Amherst Wastewater Treatment Plant

The Amherst Wastewater Treatment Plant (AWTP) located in Amherst, Ohio, had two TFs operating in series with no intermediate clarification. As such, they were considered a single-stage TF system. The filters were each 40 feet wide, 90 feet long, and 17 feet deep, with plastic cross-flow media.

At the time of the study, the plant was operating at a design flow of 864 m^3/d (2 million gallons per day, MGD) with a hydraulic loading rate averaging 23.0 m^3/m^2/d (565 gpd/ft^2). The plant was required to meet an effluent ammonia nitrogen limit of 6 mg/L in the winter and 3 mg/L during the summer. Temperatures for October through May ranged between 8° and 15° C (46EF and 59EF), while the summer month temperatures ranged between 17° and 20° C (63EF and 68EF).

Average monthly effluent ammonia nitrogen values during colder temperature periods varied from 1.8 to 4.9 mg/L. The AWTP results indicated a temperature dependency for nitrification below 15° C (59EF). However, the treatment plant consistently met ammonia removal requirements at loadings generally associated with nitrification design practices.

Results from full-scale studies indicate an improvement in performance when recirculation was practiced using rock or slag media. Specific surface area also has an effect on nitrification—higher specific areas for plastic media enable nitrification at higher volumetric loadings. Another factor favoring plastic media filters is their enhanced oxygen transfer.

Two-Stage Nitrification—Allentown, Pennsylvania

A treatment facility in Allentown, Pennsylvania, was required to meet effluent ammonia nitrogen limits of 3 mg/L in the warmer months and 9 mg/L during colder months. This facility was designed for an average flow of 17,280 m^3/d (40 MGD) with an effluent BOD_5 limit of 30 mg/L.

The various unit processes in this facility included screening, grit removal, primary clarification, first-stage TF, intermediate clarification, second-stage TF, final clarification, and chlorine disinfection.

The first stage had four plastic media TFs in parallel, while the second stage had a single large rock filter. A recycle ratio of 0.2:1 was practiced only on the second-stage TF. Temperatures during the warmer months ranged between 17° C and 19° C and during the colder months temperatures varied from 11° to 16° C.

The BOD_5 volumetric loading in the first stage during the study period was high, averaging 330 g/m^3/d (66 lb/1,000 ft^3/d), with an equivalent NH_4-N loading of 33,5 g/m^3/d (6.7 lb/1,000 ft^3/d). The average first-stage effluent BOD_5 concentrations during warmer and colder periods were 50 and 73 mg/L, respectively, with associated NH_4-N levels of 10.0 and 11.4 mg/L, respectively.

The BOD_5 loading in the second stage averaged 42.5 g/m^2/d (8.5 lb/1,000 ft^2/d). The average monthly effluent BOD_5 concentration was consistent throughout the study year, ranging between 6 and 18 mg/L. The effluent NH_4-N level averaged 4.7 mg/L during the warmer months and 5.9 mg/L during the colder months. This plant was able to consistently meet its effluent BOD_5 standard and ammonia-nitrogen limits throughout the study.

Nitrification process reliability is directly related to carbonaceous BOD (CBOD) loading. Low levels of organics in the influent to two-stage, attached-growth reactors can potentially eliminate the need for intermediate solid-liquid separation between the stages. Short-circuiting is less of a concern because clogging of voids in the media is also reduced.

In the absence of significant $CBOD_5$ loadings (e.g., in the second stage of a two-stage system), the rate of nitrification in attached-growth reactors is proportional to the concentration of both ammonia nitrogen and DO concentrations in the liquid phase. The reported effect of temperature is varied for TFs operating at low $CBOD_5$ levels by factors such as oxygen availability, influent and effluent ammonia nitrogen concentration, and hydraulic loading conditions.

Different media require different minimum hydraulic loadings to ensure complete wetting of the TF surface. In addition, cross-flow media offer greater oxygen transfer efficiency and higher specific surface area than vertical -flow media.

ADVANTAGES AND DISADVANTAGES

Some advantages and disadvantages of TFs are listed below:

Advantages

- Simple, reliable process.
- Suitable in areas where large tracts of land are not available for a treatment system.
- May qualify for equivalent secondary discharge standards.
- Effective in treating high concentrations of organics depending on the type of media used, and flow configuration.
- Appropriate for small- to medium-sized communities.
- High degree of performance reliability at low or stable loadings.
- Ability to handle and recover from shock loads.
- Durability of process elements.

- Low power requirements.
- Requires only a moderate level of skill and technical expertise to manage and operate the system.
- Reduction of ammonia-nitrogen concentrations in the wastewater.

Disadvantages

- Additional treatment may be needed to meet more stringent discharge standards.
- Regular operator attention needed.
- Relatively high incidence of clogging.
- Relatively low organic loadings required depending on the media.
- Limited flexibility and control in comparison with activated-sludge processes.
- Potential for vector and odor problems.
- Autotrophic bacteria (nitrifiers) are sensitive to changes in the waste stream (e.g. pH , temperature, and organics).
- Autotrophic bacteria (nitrifiers) are more sensitive to "shock loads" than other bacteria.
- Predation (i.e. fly larvae, worms, snails) decreases the nitrifying capacity of the system.

DESIGN CRITERIA

The two general types of TF nitrification configurations are single-stage and two- (or separate) stage.

- Single-stage: Carbon oxidation and nitrification take place in a single TF unit.
- Two-stage: Reduction of $CBOD_5$ occurs in the first treatment stage; nitrification occurs in the second stage.

Numerous types and combinations of treatment units are in use, depending on permit requirements, site conditions, historical development, designer experience, and feed concentrations. In general, a single-stage TF removes organic carbon or $CBOD_5$ in the upper portion of the unit and provides bacteria for nitrification in the lower portion.

There are several factors that do promote a significant amount of nitrification in a TF system. In general, TF are designed with at least a minimum effluent recycle capability to maintain a stable hydraulic loading during seasonal variations. In order to increase nitrification efficiency, recirculation and forced air ventilation should be practiced. One way of ensuring this is to use ventilation fans. Both of these actions increase the DO concentration in the bulk liquid and ultimately performance improvement has been achieved.

The value of the hydraulic loadings and organic loadings is also critical to nitrification efficiency. The value selected for minimum hydraulic loading should ensure complete media wetting under all influent conditions. The value is dependent on the media employed in the filter. Typical minimum hydraulic loading values range from 1 to 3 $m^3/m^2/hr$ (0.41-1.22 gpm/sq.ft.). Additional factors that influence nitrification efficiency include the specific hydraulic pattern of the TF media and the retention time of the wastewater within the plastic media. Plastic media with crossflow characteristics, when compared to vertical flow media, increase the hydraulic retention time or contact time between the biofilm and influent and provide superior oxygen transfer. The rock media typically used in Tfs are about 2.5 to 10 cm (1 to 4 inches) in diameter with a recirculation ratio of 1:1.

As mentioned before, pH conditions in TF liquids below certain critical levels can affect the nitrification performance. Normally, significant pH effects can be avoided by ensuring that the effluent alkalinity is equal to or greater than 50 mg/L as $CaCO_3$. For design purposes and performance stability, it is best to maintain pH at 6.5 to 8.0. The importance of DO concentration can often mask the effects of pH and temperature on nitrification in TFs, particularly at high carbonaceous feed concentrations.

The importance of the DO concentration in the operation of all TFs highlights the need for sufficient ventilation. If enough passageways are provided, the differences in the air and wastewater temperatures and humidity differences between the ambient air and the air in the TF provide a draft. This mechanism may provide the necessary aeration requirements on occasion, but not consistently. Historically engineers have selected an appropriate BOD_5 surface loading as a function of temperature to design TFs for nitrification of municipal wastewater at high $CBOD_5$.

With regards to the feed concentrations, the number of operating TFs designed to achieve nitrification of municipal wastewater containing a high $CBOD_5$ concentration of primary treated wastewater is limited. There are as of 1991, 10 plants that achieve $CBOD_5$ removal and nitrification in single trickling filter units known as combined or single-stage units. The aforementioned recommended values for pH, temperature, hydraulic loading, effluent alkalinity, and depths of rock media can be applied to systems handling high $CBOD_5$ loads.

Table 2 demonstrates some of the design criteria recommended for trickling filters handling wastewater with low carbonaceous feed concentrations.

TABLE 2 DESIGN INFORMATION FOR LOW $CBOD_5$ SYSTEM

Design Criteria	Low $CBOD_5$ Feed Concentration System
Wastewater flow characteristics m^3/d (MGD)	
raw wastewater average flow	18,925 (5.0)
total secondary effluent average flow	21,055 (5.5)
Actual Secondary Effluent Concentrations, mg/L	
Soluble COD	27
Nitrogen available for nitrification	21
Alkalinity as $CaCO_3$	120
Trickling filter Reactor Effluent Characteristics, mg/L	
Soluble COD	20
Ammonia Nitrogen	1.5
Design Conditions/Assumptions	
Reactor temperature, EC	15
Reactor pH range	7.0-7.6
Air flow rate (at average secondary loading) kg O_2 supplied/kg 0_2 required	50

Source: U.S. EPA, 1993.

PERFORMANCE

A degree of ammonium oxidation has been achieved for many years in low or standard rate rock media trickling filters. In order for these filters to complete nitrification (90 percent ammonium removal) the organic volumetric loading rate must be limited to approximately 80 grams $BOD_5/m^3/d$ (5 lb/1000 ft^3/d).

The performance of the nitrification process depends on many factors, including availability of oxygen (i.e., adequate ventilation), level of CBOD, ammonia nitrogen concentration, media type and configuration, hydraulics of the TF, temperature, and pH.

Single-Stage Nitrification

To achieve adequate nitrification in a single-stage TF, the organic volumetric loading rate must be limited to the approximate ranges shown in Table 1. Filters with a plastic media have greater surface contact area (approximately 80 percent) per unit volume than rock or slag, and achieve the same degree of nitrification with higher organic loadings. Plastic media also provide better ventilation and improved oxygen transfer.

OPERATION AND MAINTENANCE

Although TFs are generally reliable, operating problems can be caused by increased growth of biofilm due to high organic loads, changes in wastewater characteristics, improper design, or equipment failure. If nitrification is not achieved, steps should be taken to determine the probable cause(s). The first step is to sample and analyze the TF influent wastewater for an appropriate level of pH, temperature, soluble BOD, dissolved oxygen (DO), and proper organic and hydraulic loading. The soluble BOD concentration must be low in order for autotrophic bacteria to compete with the heterotrophic bacteria. The second step involves checking the TF influent DO to ensure that the autotrophic bacteria are able to derive oxygen from that source. They can also obtain oxygen via oxygen transfer within the filter media. Excessive biological growth can minimize oxygen transfer and may also promote ponding on the filter media. The final step involves checking to ensure that the TF is receiving influent wastewater and recirculation at the proper organic and hydraulic loading.

More information on operating and maintaining trickling filters (TF) can be obtained from the U.S. EPA Wastewater Technology Fact sheet, *Trickling Filters, EPA 832-F-99-078.*

COSTS

Typical costs for a TF system are summarized in Table 3. The costs associated with operating and maintaining a TF Nitrification system are expected to be higher due to increased system size and the additional maintenance required to support the media. Nitrification is considered very site specific and as a result it is hard to determine a "general" cost. For example, two identical systems in two parts of the United States (e.g. Florida and New England) will require different tank volumes to nitrify due to temperature differences.

TABLE 3 COST SUMMARY FOR A TRICKLING FILTER

Wastewater Flow (MGD)	Construction Cost	Labor	O&M	Materials
1	0.76	0.05	0.63	0.011
10	6.34	0.23	0.36	0.004
100	63.40	1.01	1.3	0.20

Source: Adapted from Martin and Martin, 1990.
Note: Costs are in millions of dollars.

REFERENCES

Other Fact Sheets

Trickling Filters
EPA 832-F-00-014
September, 2000

Other EPA Fact Sheets can be found at the following web address:
http://www.epa.gov/owmitnet/mtbfact.htm

1. Metcalf & Eddy, Inc. 1991. Wastewater Engineering: Treatment, Disposal, and Reuse. 3d ed. The McGraw-Hill Companies. New York, New York.

2. Mulligan, T. J. and O. K. Scheible. 1990. "Upgrading Small Community Wastewater Treatment Systems for Nitrification." HydroQual, Inc. Mahwah, New Jersey.

3. Parker, D.S., M.P., Lutz, and A.M., Pratt. 1990. New Trickling Filter Applications in the U.S.A. Water Sci. Tech. 22(1/2):215.

4. Parker, D.S. and T. Richards. 1986. Nitrification in Trickling Filters. JWPCF 58:896.

5. U.S. EPA, 1991. Assessment of Single-Stage Trickling Filter Nitrification. EPA Office of Municipal Pollution Control. Washington, D.C. EPA 430/9-91-005.

6. U.S. EPA, 1993. Manual: Nitrogen Control. EPA Office of Research and Development. Cincinnati, Ohio. EPA Office of Water. Washington, D.C. EPA/625/R-93/010.

7. Water Environment Federation (WEF). 1996. Operation of Municipal Wastewater Treatment Plants. Manual of Practice No. 11. 5th ed. vol. 2. WEF. Alexandria, Virginia.

8. Water Environment Federation (WEF) and American Society of Civil Engineers (ASCE). 1998. Design of Municipal Wastewater Treatment Plants. Manual of Practice No. 8. vol. 2. WEF. Alexandria, Virginia.

ADDITIONAL INFORMATION

Danbury Wastewater Treatment Plant
Public Works Department
Danbury, CT 06810

Hudson Wastewater Treatment Facility
1 Municipal Drive
Hudson, MA 01749

John Mainini, Director
Milford STP
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Milford, MA 01757

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This fact sheet was developed in cooperation with the National Small Flows Clearinghouse, whose services are greatly appreciated.

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