DESIGN AND PERFORMANCE OF SLOW SAND FILTERS IN THE PACIFIC NORTHWEST

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Slow sand filtration was introduced to the United States in the late 1800's, and a number of plants were built. However, George Fuller's studies at Louisville in the 1890's showed that pretreatment including coagulation and sedimentation could prepare turbid water for successful treatment by rapid sand filtration. In the decades that followed, rapid sand filtration became the process of choice for most water utilities. Interest in slow sand filtration waned, and in some communities those filters were replaced by rapid sand filters.

Promulgation of the Surface Water Treatment Rule is expected to result in construction of several hundred slow sand filter plants, Most of these are likely to be built in small communities where the simplicity of the process has its greatest appeal. Guidance on slow sand filter design and operation in the USA is somewhat limited. "Recommended Standards for Water Works" (1982) commonly referred to as Ten State Standards (TSS) contains some recommendations for slow rate gravity filters. The International Reference Centre for Community Water Supply and Sanitation (IRC) has published a manual on slow sand filtration.

This paper was prepared as a review of slow sand filtration design and operating practices at 13 filtration plants constructed between 1958 and 1988 in the Pacific Northwest. It represents an attempt to learn from the past in order to do a better job in the future. Among the topics presented are plant construction features, including media characteristics, filter design, and hydraulics; water quality; and operation and maintenance practices. Narrative descriptions of each plant are given, and some specific design and operating examples are presented. Data from the plants have been tabulated so that frequently observed or common characteristics of design and operation can be noted. Finally, some comments are made about recent design and operating practices, in order to assist those who will design or operate slow sand filters in coming years. Slezak and Sims (1984) reported on a survey of slow sand filtration in the United States. They found that three quarters of the plants responding to their questionnaire treated lake water. One third of

Paper presented at Annual Conference of the American Water Works Association, June 1989, Los Angeles, CA, USA the plants ranged in age from 0 to 25 years and could be considered to represent modern thinking on slow sand filters. Only one of the plants in their list of facilities that responded to the survey was located in the Pacific Northwest. Thus there should be little overlap between their survey and this one.

TREATMENT PLANT DESCRIPTIONS

Community A.

This plant has three filter beds, one of 18,000 sq ft and two of 20,000 sq. ft. Each filter is preceded by a sedimentation basin about one eighth its size. Stream water is fed to the filters by gravity. An infiltration well can provide extra water if needed. Filtration rate is not monitored or controlled for individual filters. The only flow meter is on the line feeding into the distribution system. In 1976, when this filter was constructed, fine mine tailings were used as the filter material. Two years later this media was removed and replaced with a coarser sand that eventually compacted. The filters were again rebuilt in October, 1988 and now contain approximately 30 inches of 0.4 mm e.s. (effective size) sand having a uniformity coefficient of 4.5. This sand was pilot tested and extensively washed before being placed in the filter beds.

Influent to two of the filters is based on the water level in the sand beds and is regulated automatically. The third filter, which is not used in winter, is operated manually. Flow from the filters is controlled on the basis of the water level in storage reservoirs. The motorized butterfly valves on the effluent lines have been observed to cause the filters to stop and start on intervals as short as ten minutes.

Cleaning practice before resanding (replacement of sand) had involved use of a road grader and front end loader for scraping and moving the top layer of sand. Winter cleaning operations occasionally required use of a crawler tractor and ripper to break up the sand when it froze after the filter had been drained. When the filter was resanded, a compacted layer of sand having the consistency of hard pan was observed in some parts of the filter beds, about 10 inches below the surface. Before resanding, the filter exhibited less than 10 percent removal of particles in the <u>Giardia</u> cyst size range. Since resanding, removal of particles in that size range has been about 90 percent.

Community B

This plant consists of two filters, each having an area of 17,000 sq ft. Sedimentation ponds adjacent to each filter are separated from the filters by wooden baffle walls. The raw water source is gravity fed from a stream. The flow from the filters is controlled by motorized butterfly valves on each filter, with level controls in the clearwell operating the valves. Under conditions of low demand, the filters are turned on and off frequently because of this arrangement. No provision exists for monitoring or manually controlling flow rates from each filter. Although these filters can be refilled from the bottom with potable water after scraping or resanding, this can be done only by diverting the flow of filtered water from the other filter bed. Backfilling with potable water in effect shuts down production of water for the community, and the operator has been reluctant to shut off the flow of water to storage and distribution. As a result of this design approach, backfilling with potable water is not practical in Community B. Each filter is cleaned about two times per year. Cleaning one filter bed requires approximately 72 to 96 hours of labor. High school athletes have sometimes provided the labor needed for filter scraping. After they are cleaned, the filters are refilled from the top rather than from the bottom as is usually recommended to prevent air binding, but the operators have reported no problems related to this practice.

The plant has had one coliform MCL violation in the past three years. Filtered water turbidity is consistently below 1 NTU (Nephelometric Turbidity Unit). Copper sulfate is used to control algae in the summer.

Community C

Water from a small creek is gravity fed to a 600 sq ft filter that serves a ski area. A capacity of about 43,000 gallons per day is used to provide water for about 2500 day use visitors. A single 20 ft x 30 ft x 8 ft filter is next to a 20 ft x 8 ft x 8 ft sedimentation basin. Both are covered by a concrete block building with a roof of steel I beam and wood frame construction. Raw water is continually applied to the filter, with a manual rate control. Flow from the filter is controlled by the level of water in a small wet well at the pump house. This sometimes results in abrupt on-off operation.

This is a winter use facility, and cleaning is done about twice per winter. Each manual cleaning requires about two hours of labor. Because snow accumulates over the filter building and acts as insulation, freezing is not a problem in the winter.

The lack of an overflow weir at this plant creates the potential for air binding. Filling the filter from the top after scraping could further increase the opportunity for air binding problems. The high humidity inside the structure has resulted in severe rotting of some of the wooden rafters.

Community D

This community had a problem with giardiasis in 1983, but no new cases have been reported since the plant started operating in 1986. This 0.22 MGD plant has three beds, each 20 ft x 37.5 ft, of concrete construction. A metal building with steel and wood framing covers the filters. Raw water is fed by gravity from a nearby stream. Filtration rate is controlled at the effluent, automatically, and involves on-off operation. The plant has filter-to-waste capability and can be backfilled with potable water. A pilot study was conducted before this facility was built.

The three filter beds at this plant have been cleaned only about two or three times per year so far, and routine operation takes approximately one hour per day. The plant has a below grade vault for the pipe gallery, controls, turbidimeter and chlorinator (liquid sodium hypochlorite feeder). Access is by a ladder. Because of the slope of the ground at this site, if the pipe gallery and control room had been located on the opposite side of the filter building, the control room floor would have been at ground level. This would have enabled the operator to walk directly into the control room instead of climbing down into it. Ground level access is preferable, as it would have eliminated the potential for flooding of the control room and could have provided better ventilation for this area. Use of insulated plywood panel covers supported one foot above the water surface has helped prevent ice formation on the filters in the winter and has helped control moisture in the filter building.

The sand used in construction of the filter bed was not well washed and had an excessive amount of fines. Effluent turbidity exceeded 1 NTU for over a year and more recently average effluent turbidity (0.77 NTU) has been almost twice the average influent turbidity at this plant.

Communities E and F

These plants are similar and serve communities of about 300 persons each. Each is a single circular concrete structure. Plant E produces up to 0.19 MGD from a 24 ft filter bed whereas Plant F produces 0.23 MGD from a 38 ft diameter bed. Both treat stream water fed to the plants by gravity. Water is introduced around the perimeter of each open filter, which tends to prevent freezing in the area near the filter walls. This helps to protect the structure from ice damage, but ice still could cause problems if the filters had to be cleaned in the winter. These filters have an unusual flow control system. At each plant, filtered water flows into a clearwell that can hold water up to an elevation as high as the top of the supernatant water over the filter. As the water level in the clear well rises above the point at which treated water is discharged into the clearwell, the filtration rategradually slows. Filtration would stop when the water levels in the filter and clear well were equal. Filtration would resume gradually when the level dropped in the clearwell, and the rate would increase as the head differential increased. Filter plants having this kind of variable flow rate should be equipped with flow paced chlorinators to assure adequate disinfection. At these two plants, chlorinators are activated by water meters on the filter effluent lines.

The similarities and differences of Plants E and F provide an interesting comparison. Media depths (32 and 36 inches) and effective sizes (0.37 and 0.36 mm) are similar. Filtration rates are quite different. Plant E operates in the 0.24 to 0.7 m/hr range, whereas Plant F operates in the 0.12 to 0.32 m/hr range. Influent turbidity at Plant E was 0.09 to 4.2 NTU and averaged 0.8 NTU. The effluent ranged from 0.7 to 3.1, averaging 0.53 NTU. At Plant F the influent water ranged from 0.03 to 1.18 NTU and averaged 0.4 NTU. The filtered water varied from 0.04 to 0.52 NTU, averaging 0.1 NTU. Plant E, operating at higher rates, is scraped about 10 times per year, whereas Plant F is scraped about 4 times per year.

Filters of this design are simple to operate, but a few comments are in order. Flow proportioning of chlorine during times of very low flow may be difficult. When clearwells are designed to hold water up to the elevation of the supernatant water in the filter, the discharge pipe from the filter should be as high as thefilter sand, so media can not be dewatered if raw water flow is interrupted. The perimeter piping for introducing raw water to the filter helps to retard ice formation around the edge of the filter, but some freezing problems have been encountered in shaded areas with filters of this type.

Community G

This facility was built to provide filtration for previously unfiltered river water. An infiltration well provides some pretreatment, keeping large debris such as evergreen needles and cone fragments and leaf litter out of the filter. A pilot study conducted before construction indicated that slow sand filtration would produce good water quality, and that runs might last as long as six months.

This filter is performing as well as originally expected by all parties involved. One small design change suggested for other plants is to provide filter-to-waste individually for each filter. At this plant the filter-to-waste flow is diverted after the two filter effluent streams merge, so wasting filtered water results in producing no water for consumption.

The earth dike, open filter design provided Community G with 0.28 MGD of filtration capacity with both filters operating at a rate of 0.12 m/hr for $83,000. With this conservative filtration rate, one filter could provide 0.28 MGD by operating at 0.24 m/hr, a rate within the guidelines of the Ten State Standards. This permits removing one filter from service for maintenance even if the full plant capacity is needed.

Water quality from this filter plant has generally been satisfactory. A landslide in the watershed caused the raw water turbidity to rise to 40 NTU and filtered water turbidity then rose to the 3 to 4 NTU range. Raw water turbidity typically is 1 NTU, and filtered water turbidity averages 0.6. Operators at this plant report some initial high turbidities for one to two days after the filter is scraped and returned to service. When the filter was placed into service in late 1986, the insufficiently washed sand contributed turbidity to the filtered water. This continued until late in 1987. Since then performance has been satisfactory.

Community H

At Community H a pilot plant study preceded construction of the filtration plant. This facility has two open filters with concrete walls. Raw water is pumped to the filter, and effluent control is related to the level of water in a storage reservoir.

Raw water averages 1 NTU, and filtered water averages 0.40 NTU. The filter runs typically last 5 or 6 months. The operator routinely rakes the surface of the filter between scrapings.

The operator would like to have "walk-in" access at this plant. The concrete box configuration of the filter beds does not permit this. For filters of this size (29 ft x 85 ft) provision of an inclined plane wall at one end would enable all-terrain vehicles or lawn tractors with flotation tires to be driven into the slow sand filter. This would make hauling out the scraped sand a much easier job for the operator.

This filter is performing as well as expected. The plant was built at a cost of slightly less than $200,000 for 0.34 MGD of capacity with both filters operating at 0.17 m/hr.

Community I

Slow sand filtration was installed in 1958, when a 5 acre open filter was built. Population grew, and in 1970 another 5 acre filter was constructed. Earth embankment construction was used each time. River water flows by gravity to this plant. These filters have the capability to drain supernatant water and to filter-to-waste, but they are not backfilled with potable water after scraping. Filtration rates range from 0.32 to 0.56 m/hr. This plant has the capacity to filter 100 to 110 MGD through the sand beds, but because of leakage into the soil beneath the beds, the flow of water provided to the community may be only as much as half of the applied flow. Lining the beds to prevent leakage could have alleviated this, but that would have increased the construction cost. Galvanized pipe underdrains were used, but in the future PVC pipe probably would be selected for underdrains.

This plant is simple to operate, and inexpensive. Annual operation and maintenance cost for providing water to about 100,000 people is approximately $200,000. Mechanical scraping equipment is used, including a custom-built machine with flotation tires that scrapes the sand and elevates it into a dump truck. Scraping is done about seven times per year. Some problems are encountered with algae, and copper sulfate is added as needed to control these. The operating strategy for this plant calls for shutting down the intake if the river water turbidity exceeds 8 NTU.

Community J

Slow sand filtration was installed in this community in two stages, beginning in 1975, when two filters were built. These earth dike filters, each having an area of 32,600 sq ft, had some leakage through the clay liners. When a third filter of the same area was built in 1987, earth dike construction was again used, but a cement mortar (Gunite) liner was applied. Filtration rate through the original filters is 0.43 m/hr, whereas it is 0.22 m/hr through the new filter designed to reduce leakage.

Filter sand was obtained locally, and the gradual washing out of fines in the sand caused the effluent to be turbid for a while after startup of the filter in 1987. Filter runs vary in length from one month to one year. Scraping is done with mechanical equipment. Unlike most other plants, which chlorinate only after filtration, this facility chlorinates both before and after.

Community K

Two circular concrete, covered, slow sand filters were built at this community in 1987, without a prior pilot plant study. No long term records of raw water turbidity were available, although the river is subject to high turbidities after sustained rainfall. An infiltration gallery was built, and water is pumped from there to the filters. This plant was designed to operate at 0.39 m/hr and has influent flow rate control for the 26 ft diameter filters. Ithas filter-to-waste capability, can be backfilled with potable water, and has supernatant drainage capability. Each filter has a flow indicator and head loss indicator. Problems with automatic influent flow controls have resulted in manual operation of raw water pumps.

Water quality has been a problem at this plant. Raw water turbidity ranges from 0.2 to 100 NTU. Per capita consumption appears to exceed 200 gallons per day at times, although part of the water production is perhaps being lost through leaks in the distribution system.

Community L

Slow sand filtration was installed in this community in 1988, following a pilot plant study. Lake water is supplied by gravity to this plant. Two concrete, open, cylindrical filters, each 30 ft in diameter, can provide 0.20 MGD when operated at 0.24 m/hr. These filters have effluent rate control, can be backfilled with potable water, have supernatant drains, and can be operated in filter-to-waste mode. Each has a flow indicator and head loss indicator.

This filtration plant treats a high quality water that averages 0.3 NTU with a range of 0.17 to 0.74. Filtered water turbidity averages 0.23 NTU and varies between 0.07 and 0.6 NTU. Daily operation takes about 0.7 hour, and each filter is cleaned three times per year, requiring 4 hours of labor per cleaning.

Community M

Four rectangular, covered, concrete filters were built in Community M in 1988. Each filter is 20 ft x 65 ft. Plant capacity at 0.24 m/hr is 0.75 MGD. These filters have filter-to-waste, head loss indicators, rate of flow indicators, and can be backfilled after scraping.

Daily operation requires about 1.5 hours, and the filters are scraped about two to four times per year. Logging and rainstorms influence the raw water turbidity in the river, which varies from 1.2 to 10 NTU, averaging 2.6. Filtered water has ranged from 0.54 to 2.1 NTU, with an average of 1.1 NTU. Washing out of fines from the filter sand may have contributed to filtered water turbidity.

DISCUSSION

Construction

Thirteen communities are included in Table 1, which gives data on community size and plant construction. Earth dike construction was used in five communities. Concrete construction is more popular, and at two plants lined earth dikes have been used to limit leakage from the filter. Although parts of Oregon, Washington and especially Idaho have cold winters, only 4 of 13 filters are covered. In part this reflects construction in the milder areas of Oregon and Washington, and in part this is related to a technique developed by engineers to retard freezing at the perimeter of the filter bed. Although recommended design practice usually calls for more than one filter bed, three plants have just one filter. This may not be a fatal flaw if the community has abundant treated water storage and if lengthy maintenance such as resanding can be done at times of minimum flow. Slow sand filters should be used to treat very high quality raw water, but of the 13 communities, 12 used streams or rivers of variable quality and one had a lake for its water source. This will be noted again in the section on water quality.

Action Design Vs. Design Standards

Slow sand filtration involves no coagulation or other chemical pretreatment as it is usually practiced. In some instances water may be treated by plain sedimentation (no coagulation) or by microstrainers before being applied to slow sand filters. Such practices do not change the surface chemistry of the particles applied to the filter, but the flux of influent particulate matter may be reduced by such pretreatment. Because operators have a very limited capability to enhance the performance of slow sand filters, proper design of these facilities is important. If the design engineer has not adhered to generally accepted design factors, performance may not attain expectations.

With this in mind, recommendations for slow sand filter design are reviewed and compared to the 13 plants described in this paper. Table 2 lists recommendations for filter design from the Ten State Standards (TSS) and Slow Sand Filtration for Community Water Supply (the IRC manual) (Visscher, et al., 1987). The recommended filtration rate in the TSS is 0.08 to 0.24 m/hr. The IRC recommends 0.1 to 0.2 m/hr. Six of 13 plants exceed 0.30 m/hr at times. With respect to filtration rate, designers are not conservative. The two sets of guidelines are not at all in agreement on effective size of media. TSS recommends 0.30 to 0.45 mm whereas IRC recommends 0.15 to 0.30 mm. All media sizes were smaller than 0.45 mm and larger than 0.15 mm. Recommendations of the two groups for uniformity coefficient (u.c.) also are quite different, with TSS asking for equal to or less than 2.5 and IRC asking for less than 5 but preferring less than 3 for a u.c. All u.c. values were less than 5, but only four of the plants had u.c.'s equal to or less than 2.5. For filter sand depth, TSS recommends equal or greater than 30 inches, and IRC suggests 31 to 35 inches. No plant had less than 30 by design and nine had 36 inches or more. Only one plant had less than 3 feet of supernatant water recommended by both groups.

Some plants have experienced turbidity problems caused by the washing out of fine particulate matter associated with the filter media. Dirty sand should not be used as filter media. Concerning sand used for this purpose, the AWWA Standard for Filtering Material, B100-89 (AWWA, 1989), states. "The silica sand shall be visibly free of clay, dust, and micaceous and organic matter." The standard further states that the sand shall be within "... a maximum of 2 percent minus No. 200 (0.074 mm) material by washing as determined by ASTM C 117 ..."

The greatest departure from recommended practice occurs when engineers design filtration rates. Typically water demand varies for time to time, and if slow sand filtration is effective at recommended rates but ineffective at the higher design rate, waterutility data on flows, turbidities, and bacteriological test results may reveal this. One remedy to such a situation would be to expand the existing plant, if conditions permit, using operating data from times when water quality was acceptable as the guide for the new design.

Hydraulic Design

A number of hydraulic design features are helpful to the plant operator with respect to managing and controlling slow sand filters although not all might be considered important for reasons related to water quality and public health. Aspects of hydraulic design are listed in Table 3. A cross-sectional view of a slow sand filter is shown in Figure 1. Filter-to-waste capability enables operators to waste poor quality water during the filter ripening period that may follow scraping. Poor quality would definitely be expected to follow resanding, when a foot or more of sand is added to the filter after repeated scrapings. Only two plants lacked filter-to-waste capability. Rate of flow indicators enable an operator to be aware of and in control of filtration rates, yet four plants lacked these or had flow indicators for total flow rather than for individual filters. Only six of 13 had overflow weir arrangements to reduce the tendency for air binding to occur and to prevent unintended dewatering of the filter bed, and only six of 13 had capability to backfill with potable water after the filter had been drained. The latter procedure also prevents air binding upon startup of a filter. The public health argument for these features may not be clear cut, but they certainly add to operational flexibility and control or monitoring capability, as do head loss indicators, present in only six plants. Nine of the plants are subject to start-stop operation at times. Starting and stopping filters to match plant production and community water demand is not good practice regardless of the type of filtration being used. Nevertheless starting and stopping filters seems to be a typical practice in many small systems.

Water Quality

At slow sand filtration plants filtered water quality is somewhat related to raw water quality (see Table 4). Four plants reported a maximum turbidity of 1.0 NTU or less, and these had maximum raw water turbidities ranging from 0.74 to 5 NTU. Seven plants reported maximum filtered water turbidity from 1.2 to 10 NTU. Of these three had raw water from 10 to 100 NTU maximum and filtered water as high as 2.1, 3 to 4, and 10 NTU. Three others with maximum raw water turbidities of 4.0 to 8 NTU had peak filtered water turbidities of 1.2, 1.4, and 1.6 NTU. One plant with a maximum of 4.2 in the raw water reported a peak of 3.1 NTU for filtered water. These results suggest that a substantial amount of care is needed in evaluating the suitability of source waters for slow sand filtration.

More careful consideration of European (IRC) design recommendations may be appropriate. Five of seven plants with maximum filtered water turbidity exceeding 1.0 NTU (Table 5) had filtration rates or filter media sizes exceeding the values recommended by the IRC, and one plant had both very high rates and media exceeding the 0.30 mm effective size. Two plants within IRC recommendations for filtration rate and media size had raw waters with peak turbidities of 10 NTU and 40 NTU. Of the plants having filtered water turbidities up to 1.0, one plant exceeded recommended values for both filtration rate and media size, but the peak raw water turbidity at that plant was only 1.18 NTU. The best turbidity performance appears to be related to conservative designs for filtration rate and media size, and to conservative application of the process, i.e., use with low turbidity raw water. These problems again show the need for doing pilot plant studies before designing and building slow sand filters.

Operation and Maintenance

Slow sand filters are simple to operate in good circumstances. Some operating data for this group of plants may be found in Table 6. The small plants in this group of 13 reported that daily operating chores required from 2 to 10 hours per week. This amount of time is appropriate for facilities managed by a part time operator. The small plants are cleaned manually at frequencies ranging from once per month to once per year. Two to four scrapings per year were needed at most plants. If this job requires extra labor, obtaining help for a few hours or a day or two should not be difficult in most small communities, because scraping does not involve skilled labor. One noteworthy maintenance problem was the freezing of a dewatered sand bed. Apparently the weather turned cold after the filter had been dewatered and the damp sand froze. Mechanical equipment had to be used to break up the ice-sand aggregate. Scraping slow sand filters just before onset of winter weather would increase the possibility of operating open slow sand filters all winter without scraping.

SUMMARY

A number of excellent concepts in slow sand filter construction have been observed.

1. A membrane liner at an open filter was used to prevent leakage and hold down project cost.

2. Introducing water at the perimeter of slow sand filters has retarded icing at the edges of the structures in open concrete filters.

3. Covering the filter boxes with insulated panels had helped reduce moisture problems in an enclosed filter.

4. Use of infiltration wells or galleries has served to remove large debris from the water before it is introduced to the filters.

5. Use of plastic pipe in underdrains eliminates corrosion problems.

A number of problems have been noted and are mentioned, along with suggestions for improvement.

1. Pilot plant studies were done at only 5 of 13 locations. No pilot work was done at the site having the 100 NTU raw water peaks. Slow sand filter design should be preceded by a pilot plant investigation in most instances.

2. Engineers are often designing slow sand filters to operate at rates higher than those recommended by the TSS and IRC. Rates should be in the range of recommended values unless a pilot plant study shows that higher rates provide acceptable water quality.

3. Designers should be careful about the effective sizes and uniformity coefficient of media used in slow sand

filtration plants. A conservative approach would be to use the IRC values of e.s. (0.15 to 0.30 mm) and a u.c. of less than 3, unless pilot plant data verify that another media specification is satisfactory.

4. Sand with an excessive clay or dust content has been obtained from some local sand and gravel suppliers. This has caused turbid filtered water for extended periods of time after the plants begin operating. If local sand is used, it should be washed very thoroughly and tested in a pilot filter to verify the efficacy of the washing procedure and the acceptability of the sand.

5. Raw water turbidity is too high in some cases. A properly planned and conducted pilot study should define the upper limit of raw water turbidity for effective operation of a slow sand filter at a given location.

6. Some plants are being designed with only one filter. Lack of redundancy could cause problems when the filter is out of service long enough for the supply of treated water to be used up. Redundancy should always be built in, even if it involves merely dividing the existing facility in two so the two halves can be run independently.

7. Some filters are being built without effluent weirs to prevent accidental filter dewatering. Engineers should consider the plant operator and should not omit features that can prevent occurrence of operating problems.

8. Some filter plants are being built in a way that requires the operator to climb down an access ladder to get to the turbidimeter, chlorinator, and controls. This is an invitation to accidents and to neglect of the plant. Again, the designer should consider the plant operator.

9. Designers may need to consider the benefit of the simplicity, low cost and reliability of manual flow controls vs. the benefits of operating flexibility provided by automatic controls for times when a slow sand filter plant is not staffed by an operator.

CONCLUSION

Construction of slow sand filters is expected to occur at a brisk pace in the future. If engineers try to incorporate good design features and are careful not to include problematic aspects, effective plants that are easy to operate can be built.

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Table 1

Slow Sand Filter Plant Construction

Community	Population	Capacity mgd	Construction		Covered	No. of Cells	Shape	Dimensions	Water Source	Delivery
			Date	Material						
A	3,000	4.0	1976	Earth dike	No	3	rect.	70' x 280'	Stream/ River	Gravity/ Pump
B	1,200	1.56	1970	Earth dike	No	2	rect.	17,000 sq. ft. each	Stream	Gravity
C	2,500	0.043	1974	Concrete	Yes	1	rect.	20' x 30'	Stream	Gravity
	ski resort: non community, transient									
D	300	0.22	1985	Concrete	Yes	3	rect.	20' x 37.5'	Stream	Gravity
E	300	0.19	1968	Concrete	No	1	circ.	24' diam.	Stream	Gravity
F	300	0.23	1968	Concrete	No	1	circ.	38' diam	Stream	Gravity
G	400	0.28	1986	Earth dike	No	2	square	45' x 45'	Infilt. Well	Pumped
H	1,400	0.34	1987	Concrete	No	2	rect.	29' x 85'	Creek	Pumped

Table 1 (Cont'd.)

Community	Population	Capacity mgd	Construction Date	Construction Material	Covered	No. of Cells	Shape	Dimensions	Water Source	Delivery
I-1	49,000 in 1960	40-45	1958	Earth dike	No	1	rect.	5 acres	River	Gravity
I-2	68,000 in 1970, now 100,000	50-70	1970	Earth dike	No	1	rect.	5 acre	River	Gravity
J-1	3,200	8.3	1975	Earth	No	2	rect.	143' x 228'	River	Gravity
J-2	5,000	4.2	1987	Earth dike Gunite Liner	No	1	rect.	143' x 228'	River	Gravity
K	300	0.24	1987	Concrete	Yes	2	circ.	26' diam.	Infiltration Gallery	Pumped
L	1,000	0.20	1988	Concrete	No	2	circ.	30' diam.	Lake	Gravity
M	1,000	0.75	1988	Concrete	Yes	4	rect.	20' x 65'	Wells & River	Pumped & Gravity

Table 2. Filter Designs Compared To I.R.C. and Ten State Standards Recommendations

Community	Filtration Rate		Media				Water Depth ft.	Pilot Study
	gpm/sf	m/hr	Depth inches	Effective size	Uniformity coefficient	Source		
T.S.S.	0.03-0.10	0.08-0.24	≥30	0.30-0.45	≤2.5	---	≥3	---
I.R.C.		0.1-0.2	31-35	0.15-0.30	<5, prefer <3	---	3	---
A	0.05	0.12	30	0.4	4.5	pit/washed	5	no
B	0.03	0.07	38	0.28	2.5	pit/washed	5	yes
C	0.05	0.12	30	0.21	3.3	commercial	4	no
D	0.07	0.17	48	0.2	2.6	crushed rock	5	yes
E	0.1-0.28	0.24-0.7	32	0.37	3	pit	3	no
F	0.05-0.13	0.12-0.32	36	0.36	3	pit	3	no
G	0.05	0.12	36	0.30	2.0	commercial	2.5	yes
H	0.069	0.17	30	0.23	2.3-3.0	local sand	4	yes
I-1	0.13-0.15	0.32-0.36	36	0.18-0.28	3.4-5.0	On-site crusher	4	no
I-2	0.16-0.23	0.40-0.56	36	0.18-0.28	3.4-5.0	commercial	4	no

Table 2 (Cont'd.)

Community	Filtration Rate		Media				Water Depth ft.	Pilot Study
	gpm/sf	m/hr	Depth inches	Effective size	Uniformity coefficient	Source		
J-1	0.18	0.43	36	0.25	3.3-3.4	commercial	4	no
J-2	0.09	0.22	36	0.25	3.3-3.4	commercial	4	no
K	0.16	0.39	48	0.22	20	commercial	3.5-6	yes
L	0.10	0.24	50	0.30	2.3	commercial	4	no
M	0.10	0.24	48	0.25	3.0	local	4	

Table 3

Slow Sand Filter Hydraulics

Community	Rate Control	Flow: Start/ Stop Operation	Flow Control	Overflow Weir	Backfill with Potable Water	Supernatant Drain	Filter to Waste Capability	Flow Indicator each Filter	Head Loss Indicator
A	effluent	yes	auto	no	yes	no	yes	no	no
B	effluent	yes	auto	yes concrete	yes	no	yes	no	no
C	effluent	yes	auto	no	no	no	no	yes	no
D	effluent	yes	auto	yes pipe	yes	no	yes	yes	no
E	effluent	no	manual	no	no	yes	yes	yes	no
F	effluent	no	manual	no	no	yes	yes	yes	no
G	effluent	no	auto	yes	no	yes	yes, but only both beds @ once	yes	yes
H	effluent	yes	manual	yes	no	no	yes	yes	yes

Table 3 (Cont'd.)

Community	Rate Control	Flow: Start/ Stop Operation	Flow Control	Overflow Weir	Backfill with Potable	Supernatant Drain	Filter to Waste Capability	Flow Indicator each Filter	Head Loss Indicator
I-1	effluent	no	auto	no	no	yes	yes	both combined	no
I-2									
J-1	effluent	yes	auto	no	no	no	no	both combined	no
J-2			auto				yes		
K	influent	yes	auto	no	yes	yes	yes	yes	yes
L	effluent	yes	auto	yes	yes	yes	yes	yes	yes
M	effluent	no	manual	yes	yes	yes	yes	yes	yes

Table 4

Water Quality

Community	Turbidity, NTU				Are Algae a Problem?
	Influent Water		Filtered Water		
	Range	Average	Range	Average	
A	1.6-4.0	-	0.4-1.2	-	yes
B	-	-	0.3-0.9	0.4	yes $CuSO_4$ used
C	-	5.8	-	0.85	no
D	0.07-5.0	0.4	0.5-0.9	0.77	no
E	0.09-4.2	0.8	0.7-3.1	0.53	no
F	0.03-1.18	0.4	0.04-0.52	0.1	no
G	up to 40	1	up to 3-4	0.60	yes
H	up to 2.0	1	up to 1.0	0.4	no
I-1]] I-2]	0.4 to 50 or 100 Intake shut at 8 to 10 NTU	<1.0	0.06-1.4	0.30	yes $CuSO_4$ used
J-1]] J-2]	Same raw source as Community I		0.11-1.6	0.3	yes
K	0.2 -100	0.6	0.3-10	0.45	no
L	0.17-0.74	0.30	0.07-0.6	0.23	no
M	1.2-10	2.65	0.54-2.1	1.1	no

Table 5

Filtered Turbidity vs. Raw Water Turbidity and Filter Design Factors

Filtered NTU MAX.		Raw NTU MAX.	Filtration Rate, m/hr.	Media effective size, mm
		<u>Low Filtered Turbidity Group</u>		
F	0.52	1.18	0.32*	0.36*
L	0.6	0.74	0.24	0.30
D	0.9	5	0.17	0.2
H	1.0	2.0	0.17	0.23
		<u>High Filtered Turbidity Group</u>		
A	1.2	4.0	0.12	0.4*
I	1.4	8	0.56*	0.28
J	1.6	8	0.43*	0.25
M	2.1	10	0.24	0.25
E	3.1	4.2	up to 0.7*	0.37*
G	3-4	40	0.12	0.30
K	10	100	0.39*	0.22

* Exceeds IRC recommendation

Table 6

Operation and Maintenance

Community	Daily Operation & Maintenance	Filter Cleaning Procedure				Bypass Filter During Cleaning/ Resanding	Prechlorination Used
		Method	Frequency	Potable Water Backfill after Scraping	Filter to Waste		
A	7 hr/wk	manual	2/yr	yes	no	no	no
B	7 hr/wk	manual	2/yr	no	no	no	no
C	2 hr/wk	manual	4/yr	no	no	no	no
D	7 hr/wk	manual	1/yr	yes	yes	no	no
E	4 hr/wk	manual	10/yr	yes	yes	yes	no
F	4 hr/wk	manual	4/yr	yes	yes	no/yes	no
G	4 hr/wk	manual	2/yr	no	not done	no	no
H	7 hr/wk	manual	2/yr	no	not done	no	no
I-1 I-2	56 hr/wk	mech.	7/yr	no	yes	no	no

Table 6 (Cont'd.)

Community	Daily Operation & Maintenance	Filter Cleaning Procedure				Bypass Filter During Cleaning/ Resanding	Prechlorination Used
		Method	Frequency	Potable Water Backfill after Scraping	Filter to Waste		
J-1]		mech.	1/mo	no	no (old)	no	yes
J-2]			to 1/yr		yes (new)		
K	10 hr/wk	manual	2/yr	yes	yes	no	no
L	5 hr/wk	manual	3/yr	yes	yes	no	no
M	10 hr/wk	manual	2 to 4/yr	yes	yes	no	no

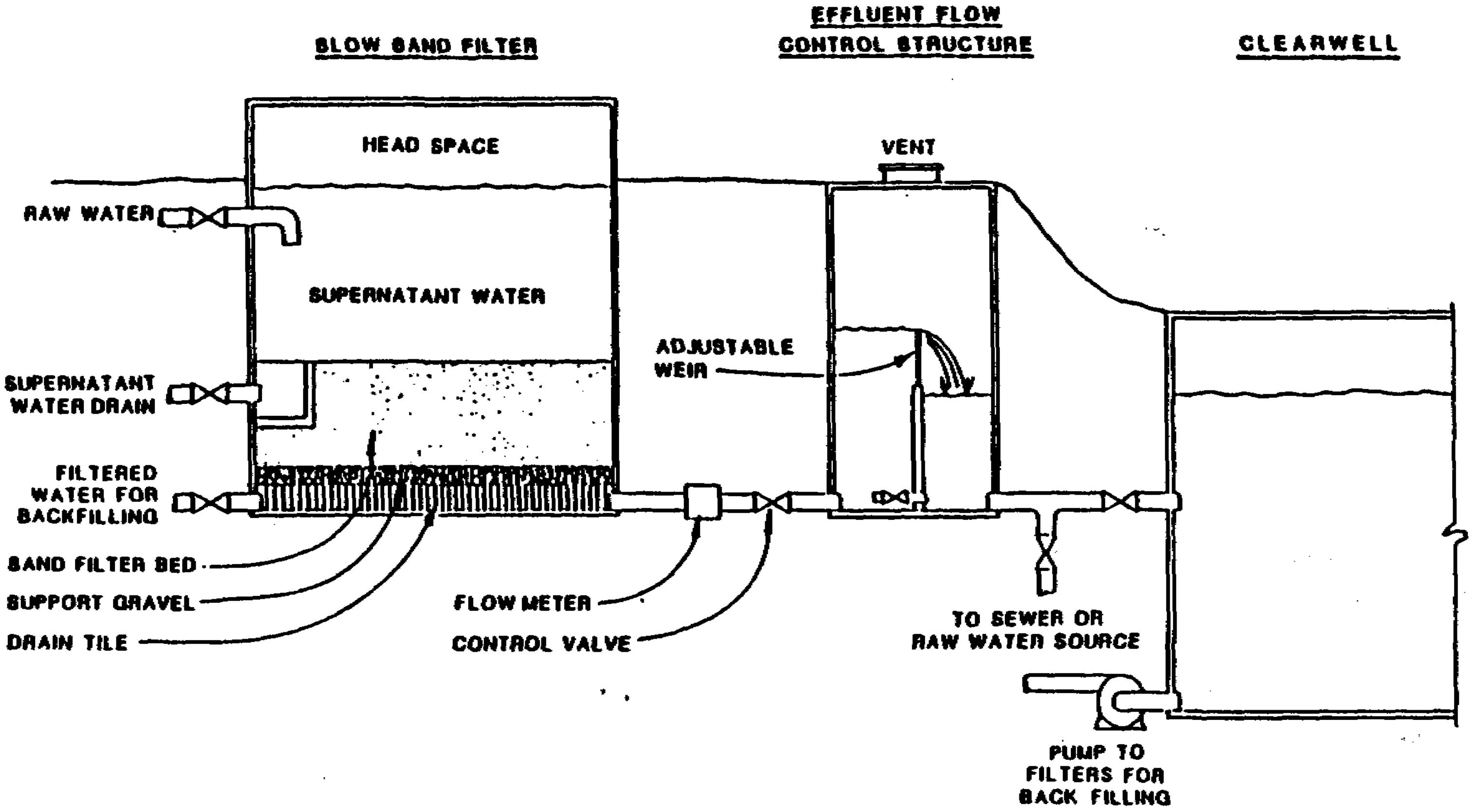

Figure 1. TYPICAL COVERED SLOW SAND-FILTER INSTALLATION

From: U.S. EPA, CERI-87-49 (By S. P. Hansen)