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HIGH RATE GRAVITY SAND FILTRATION OF WATER TO REMOVE FISH EGGS AND LARVAE

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16. ABSTRACT
A method for preventing interriver drainage basin transfer of fish, fish eggs, and fish larvae is required at the proposed Lonetree Reservoir outlet works. A limited study of high rate gravity sand filtration was conducted in a laboratory model to investigate the required parameters for removing fish eggs and larvae from a flow of water. Live fish eggs and larvae of the common carp and rainbow smelt were applied to two separate filters, one containing an effective size sand of 0.425 to 0.500 mm (0.017 to 0.020 in) and the other having an effective size sand of 1.20 to 1.70 mm (0.047 to 0.067 in). The filtration rate was held constant at 6.79×10^{-3} m/s (10 (gal/min)/ft^2) through both filters. Fish eggs preserved in formaldehyde were used after the spawning season of the fish. The filter with effective sand size of 0.425 to 0.500 mm was successful in preventing the passage of the eggs and larvae in the filtration mode. Larvae were sufficiently motile to pass through the voids in the filter with the larger size sand. Head losses and backwash rates for the filters were also investigated.

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On November 6, 1979, the Bureau of Reclamation was renamed the Water and Power Resources Service in the U.S. Department of the Interior. The new name more closely identifies the agency with its principal functions-- supplying water and power.

The text of this publication was prepared prior to adoption of the new name; all references to the Bureau of Reclamation or any derivative thereof are to be considered synonymous with the Water and Power Resources Service.

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PURPOSE

Laboratory studies were made to investigate the required parameters of a high rate gravity sand filter for removing fish eggs and fish larvae from a flow of water and to demonstrate that a sand filter can be used at the Lonetree Reservoir outlet works to prevent the passage of fish, fish eggs, and fish larvae into the Sheyenne River.

INTRODUCTION

The Garrison Diversion Unit of the Pick-Sloan Missouri Basin Program consists of an extensive, multibasin irrigation system. About 100 000 hectares (250 000 acres) in east-central North Dakota will be served by the system. The water will be withdrawn from the Missouri River and delivered to the farmland through a series of pumping plants, reservoirs, and canals. The land to be served lies in the Souris, Sheyenne, James, and Wild Rice River drainages. The James River is a tributary of the Missouri; the Sheyenne and Wild Rice Rivers are tributaries of the Red River of the North. The Souris River and the Red River of the North both flow into Canada.

The Lonetree Reservoir will be an integral part of the system. This reservoir will receive water from the Missouri River via the McClusky Canal. An outlet works will be required at the reservoir for municipal and industrial releases and streamflow augmentation into the Sheyenne River. The flow through the outlet works will be 0.57 m^3/s (20 ft^3/s) with future enlarged discharges of up to 2.3 m^3/s (80 ft^3/s) being considered.

The Missouri River contains species of fish that are considered undesirable. It appears, however, that the Souris and Red River of the North may not contain all of these species. The presence of the undesirable fish might reduce the value of affected waters for waterfowl and as a commercial and sports fishery [1].[1]

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[1] Numbers in brackets refer to literature cited in the bibliography.

For these reasons, it has been assumed that no fish, fish eggs, or fish larvae migration through the Lonetree Reservoir outlet works into the Sheyenne River will be tolerated.

INVESTIGATIONS

Methods for restricting the downstream distribution of fish in a watercourse were investigated for this study. These methods were grouped into two general categories:

1. Physical removal processes

2. Processes proving lethal to the fish and eggs

A process of physically removing the fish and eggs from a stream was chosen over any process that would be lethal to the fish and eggs because of the comparatively higher reliability, lower operating costs, and simpler operation.

The species of fish which will be of concern at the Lonetree Reservoir outlet works have eggs which appear to range from approximately 1 to 2 mm (0.040 to 00.080 in) in diameter [2]. The larvae of some of these species may have a minimum cross-sectional diameter of 0.35 mm (0.014 in) [3]. None of the physical removal processes investigated allowed selective removal of fish and eggs of this size from other organic and inorganic matter in a streamflow. Therefore, the fish and egg removal has been viewed as a suspended solids removal process in this study. In addition, the motility of the fish larvae is a very important consideration.

The physical removal process chosen must meet the stringent requirement of removing 100 percent of the suspended solid material of 0.35 mm (0.014 in) in diameter. It is felt that this can be obtained only with very strict operational control, no matter what treatment is used. This matter is further discussed in the conclusions section.

Conventional methods used to remove suspended solids from water include mechanical screens; chemical addition, coagulation, and settling; cartridge filters; ultrafiltration;

and sand or multimedia filtration. All of these methods were carefully considered independently and in combination with each other with respect to capital costs, operational costs, space requirements, flow requirements, and the 100-percent fish and egg removal requirement.

Also considered was the recommendation by the International Garrison Diversion Study Board (whose purpose was to investigate and advise on environmental matters of the Garrison Diversion Unit) to the International Joint Commission that a suitable sand filter be used at the Lonetree Reservoir outlet works to eliminate the transfer of fish, fish eggs, and fish larvae to the Sheyenne River [12].

Based on these considerations, mechanical screening plus high rate gravity sand filtration was considered the best possible treatment. The mechanical screening will remove the large suspended solid material (including small fish, algae, leaves, etc.), and the high rate sand filters will remove the small suspended solids including the fish eggs and larvae.

The literature has been investigated to determine whether sand filters have previously been used to remove small living organisms which could be compared to the fish eggs and larvae. The literature search resulted in very few published studies on the subject. One study has investigated the effectiveness of rapid sand filtration for removal of nematodes [4]. Nematodes are very thin, thread-like, worm-like organisms with a length of 0.16 to 2.0 mm (0.006 to 0.079 in) which are sometimes found in public water supplies. The study concluded that dead nematodes (usually chlorinated) were totally removed by gravity filtration through a sand bed with an effective sand size of 0.5 mm (0.020 in) and a depth of 600 mm (24 in), but only approximately 25 percent of the live, motile nematodes were removed. Motile nematode removal was independent of the filtration rate.

In the pacific Northwest, salmon larvae have been reported in water wells which are located near riverbeds. These larvae have migrated from the river through the gravel aquifer and into the wells. Thus, the motility of fish larvae must be carefully considered when trying to prevent their migration.[2]

Because of the lack of previous studies using high rate filters for the removal of fish eggs and larvae, a high rate gravity sand filter model was constructed and tested. The purpose of the model in this study was to determine whether a sand filter could be used to remove fish eggs and larvae from a flow of water.

A discussion of the design of conventional high rate filters is applicable here. This information was used as a basis for designing the study model.

The major factors affecting the design of high rate filters include (1) type of filter media, (2) type of filter media backwash, (3) depth and size of filter media, and (4) flow rate through the filter.

(1) Type of filter media. - Sand is the most economical filter media, although a fine sand will not provide long filter runs between backwashings. This is because the head loss through a fine sand increases in a short time due to the deposition of suspended matter within the top 50 mm (2 in) of the media. Dual media (coal and sand) and mixed media (usually coal, sand and garnet sand) filters allow deeper penetration of suspended matter into the filter bed and thus the buildup of head loss is slower than a sand filter. This results in fewer backwashings of the filter and a savings of power and water [5].

(2) Type of filter media backwash. - Gravity filters are usually cleaned by backwashing the media which removes the suspended solids that are trapped in the media. A backwash waterflow rate capable of expanding the filter bed 20 to 50 percent is usually adequate to obtain complete cleaning of the media [6]. At the same time, the

[2] Dr. Milo Bell, University of Washington, Seattle, personal communication

backwash rate should be higher than the terminal settling velocity of the suspended matter lodged in the filter media. The rate at which the backwash must be applied to the filter media to fluidize and expand the filter bed depends on the temperature of the water, the density of the filter media, and the size of each particle composing the filter media. The size of each particle in the media is the most influencing factor determining the backwash rate. It has been shown that the required backwash rate to fluidize a filter bed increases by approximately the square of the particle size used [7, 8]. Therefore, limitations on backwash rates will affect the size of filter media particles. Sand media of a particle size 1.3 mm (0.051 in) or larger cannot be effectively backwashed using media fluidization techniques [9].

(3) Depth and size of filter media. - Currently, there are two possible basic ways to determine the depth and size of filter media, and they are (a) a pilot plant study, and (b) an educated guess from available date [5].

Conventional sand filters for treating water for domestic use range in depth from 600 to 900 mm (24 to 36 in).

The size of filter media required can be obtained by considering that generally the largest pore opening in a filter media is only about 15 percent of the media size. In practice, a filter should be able to remove by straining any particle whose diameter is greater than approximately 5 percent of the media size [9]. Of course, the limitations of filter media size by the backwash, as previously mentioned, must be realized. For sizing the filter media to remove the fish eggs and larvae at the Lonetree Reservoir outlet works using the above information, it is known that the smallest particle to be removed (larvae) is 0.35 mm (0.014 in). Thus, 0.35 mm divided by 5 percent or a filter media size of 7.0 mm (0.28 in) could be used. Note that this is far greater than the largest realistic size media of 1.3 mm (0.051 in) that could be used with a fluidized backwash.

Conventional sizes of sand filter media for treating water for domestic purposes range from 0.35 to 1.30 mm (0.014 to 0.051 in).

(4) Flow rate through the filter. - The flow rate and terminal head loss for a filter are usually selected by making economic tradeoffs between filter size, operating head requirements, and run length, all within the limits dictated by effluent quality requirements. Adequate information for making economic tradeoffs can be obtained only from pilot studies of the specific media application [10].

Flow rates through granular media filters have ranged from 1.36×10^{-3} to 20.4×10^{-3} m/s (2 to 30 (gal/min)/ft^2) depending on the degree of filtration required. Generally, the higher the flow rate through the filter, the greater the head loss buildup per unit volume of water filtered.

Based on this discussion, the following parameters were used in the filter model study and were kept constant throughout the study.

1. Silica sand was used as the filter media.

2. A water backwash with a rate sufficient to expand the sand bed was used. The actual bed expansion used for each effective size sand bed is discussed in the experimental procedure.

3. Two sizes of sand were used. Since two filter cells were available, the two sizes of sand were tested simultaneously. The smaller sand size was used in filter 1. The sand had a uniformity coefficient of 1.20 to 1.60 and an effective size of 0.425 to 0.500 mm (0.017 to 0.020 in). In filter 2, a larger sand size was used. The uniformity coefficient of the sand was not determined. The effective size was estimated at 1.20 to 1.70 mm (0.05 to 0.07 in). The depth of each sand bed used was 380 mm (15 in).

4. The flow rate through each filter was 6.79×10^{-3} m/s (10 (gal/min)/ft^2).

The filter model was constructed and tested in the hydraulic laboratory at the Engineering and Research Center. The laboratory has a large water sump in which water is stored for use in the hydraulic models. This water was used for both the filtration and backwash filter modes in this study. The water had some turbidity, 8 to 10 JTU, and quite a bit of iron in solution, presumably from corrosion of equipment in the laboratory.

The filtration tests were conducted in the summer of 1978 during the spawning season of two species of fish found in the waters near the Lonetree damsite. In this way, live fish eggs and larvae could be used in the experiment. The common carp (*Cyprinus carpio*) and the rainbow smelt (*Osmerus mordax*) were considered to have eggs and larvae of the minimum size to be encountered at the Lonetree Dam outlet works. Thus, these two species were used in this study. The Environmental Sciences Section obtained spawning specimens of these fish and the specimens were sustained in the laboratory until live eggs were obtained. The live eggs were sustained until they hatched into larvae.

Eggs preserved in formaldehyde were used in the experiment after the supply of live eggs was depleted.

EXPERIMENTAL APPARATUS

Two rectangular filter cells were constructed (fig. 1) so that two sizes of filter sand could be tested simultaneously. The cells were constructed using 12-mm (1/2-in) clear plexiglass so that the operation of each filter could be observed. Each filter had a filter area of 0.19 m^2 (2 ft^2). The filter media depth in each filter was 380 mm (15 in) and the media was supported by gravel layers. The gravel layer was composed of graded gravel 150 mm (6 in) in depth. The gravel layer and the filter media were supported by a porous plate-type underdrain.

For the filtration mode a filter influent pump for each filter was used to pump water from the laboratory sump to the filters. The water would pass through the influent pump into the influent and drainage compartment and into a distribution and backwash water collection trough. The water would then overflow the trough and be applied to the sand. It

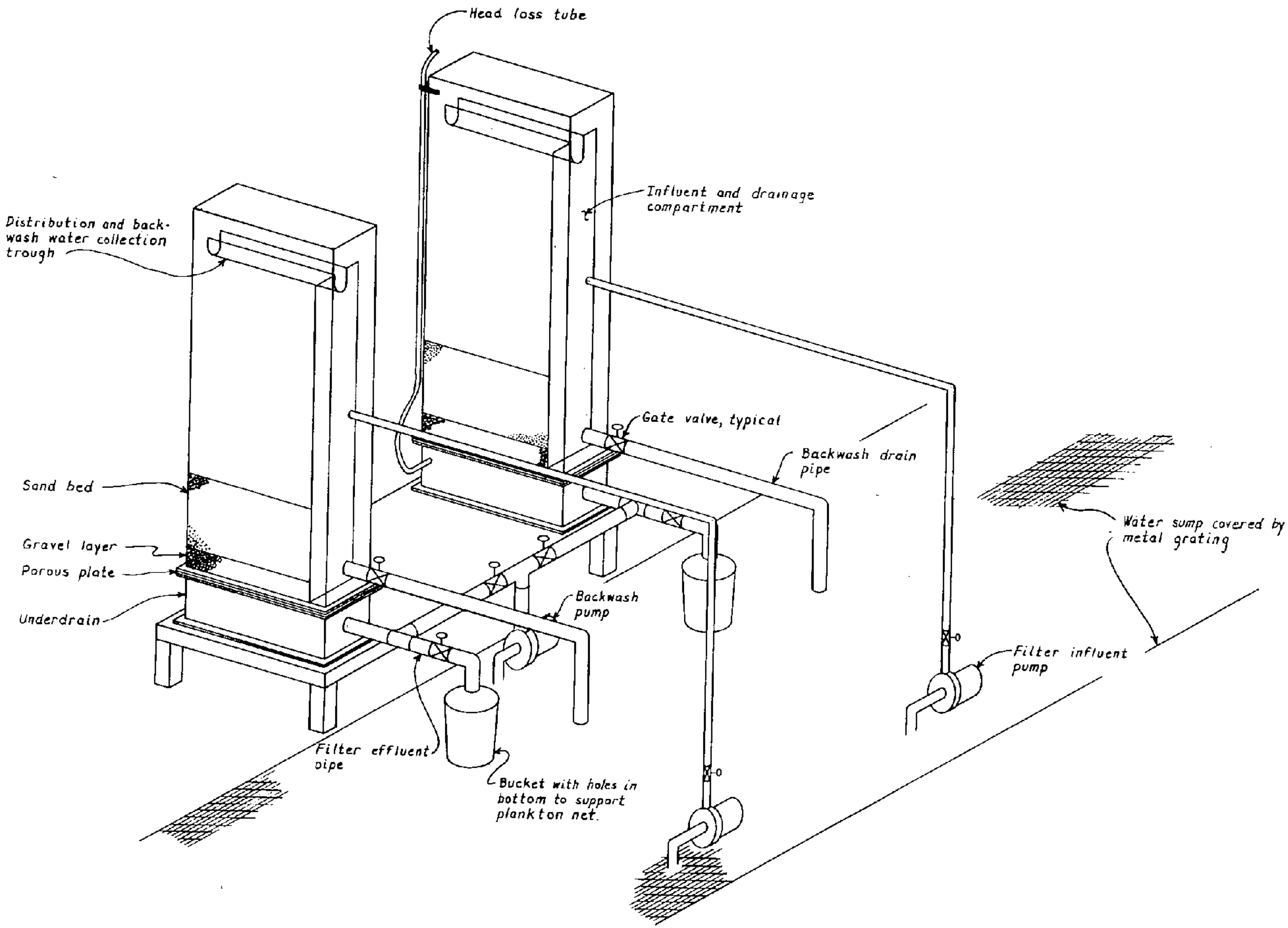

Figure 1.-Experimental apparatus.

would then filter through the sand, gravel, and porous plate into the underdrain and exit the filter through the filter effluent pipe. After leaving the filter effluent pipe, the water was filtered through a 102-μm mesh plankton net and then returned into the sump. The plankton net was used to retain any eggs or larvae which may have bypassed the filter. In this way the filter efficiency was determined. Control of the filter rate to each filter was obtained by a valve located on the discharge of each filter influent pump.

For the filter backwash mode a common backwash pump was used for each filter. Backwashing of the filters was done manually by first switching off the filter influent pump, then closing the filter effluent valve, and opening the backwash drain valve and backwash pump valve. The backwash pump would then be turned on and the backwash water would be pumped from the sump into the filter underdrain, through the gravel and sand, and up to the collection trough. The water would then drain from the trough through the influent and drainage compartment, into the backwash drainpipe, and into the sump. The rate of backwash waterflow was controlled to each filter by valves on the discharge of the backwash pump.

Filtration and backwash flow rates were measured by stopwatch timing the required time for the flow to fill a certain volume.

Head loss was measured by using a flexible tube which was connected into the filter underdrain and attached to the side of the filter cell. The height difference between the water surface in the filter and the water surface in the tube was recorded as the head loss through the filter.

Prior to the start of the filtration experiments, each filter was backwashed and approximately 25 mm (1 in) of the top of both sand beds was removed. This was done to remove most of the fines from the beds.

Figure 2 is a photograph of the filters and the related equipment. The photograph was taken while the filters were in the filtration mode.

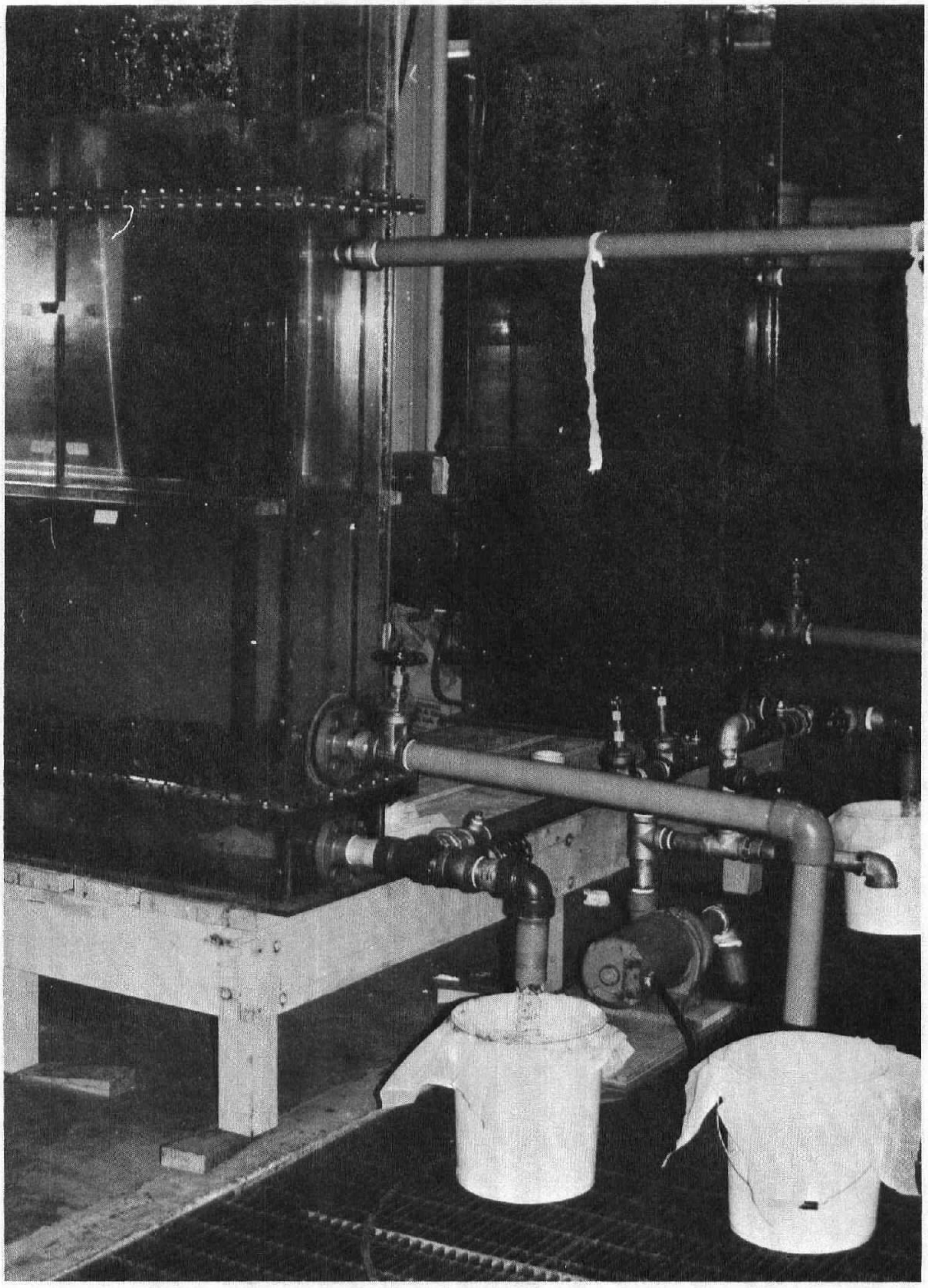

Figure 2.-Filters operating in the filtration mode.

EXPERIMENTAL PROCEDURE

The filters were operated at a constant filtration rate of 6.79×10^{-3} m/s (10 (gal/min)/ft^2) or 1.26×10^{-3} m^3/s (20 (gal/min)/ft^2) to each filter. The time allotted for this study did not allow investigation at additional filtration rates.

The filters were normally operated for 24 hours per day, 5 days per week. Thus, the filters were observed under long-term continuous operation.

The initial head loss through each filter was recorded. The head loss through the clean sand in filter 1 (0.425 to 0.500 mm (0.017 to 0.010 in) sand size) was approximately 660 mm (26 in) while the initial head loss through filter 2 (1.20 to 1.70 mm (0.047 to 0.067 in) sand size) was approximately 280 mm (11 in). Throughout the testing, no progressive buildup of the head losses through the filters was noted after backwashing. This implied that the backwashing was doing an adequate job of cleaning the media. The terminal head loss for each filter was set at approximately 1150 mm (45 in). When the head loss of either filter reached this point the filter was backwashed. This allowed a total head loss buildup of 485 mm (19 in) in filter 1 and 865 mm (34 in) in filter 2.

In determining the required backwash rates to be used in each filter two factors were considered. First, the settling velocities of the fish eggs were determined. An average settling velocity for an individual egg was found to be 732 mm/min (2.40 ft/min) at a temperature of 22 °C (72 °F). This would require a minimum backwash rate of 12.2×10^{-3} to 12.9×10^{-3} m/s (18 to 19 (gal/min)/ft^2) to carry the egg out of the filter cell. Next, the expansion height of each sand bed versus backwash flow rate was considered. Figures 3 and 4 show the percentage of bed expansion versus backwash flow rate obtained for filters 1 and 2, respectively. As a result, the backwash rate used throughout the study for filter 1 was 13.6×10^{-3} m/s (20 (gal/min)/ft^2) resulting in a bed expansion of 30 percent and the rate used for filter 2 was 38.7×10^{-3} m/s (57 (gal/min)/ft^2) resulting in a bed expansion of only 10 percent.

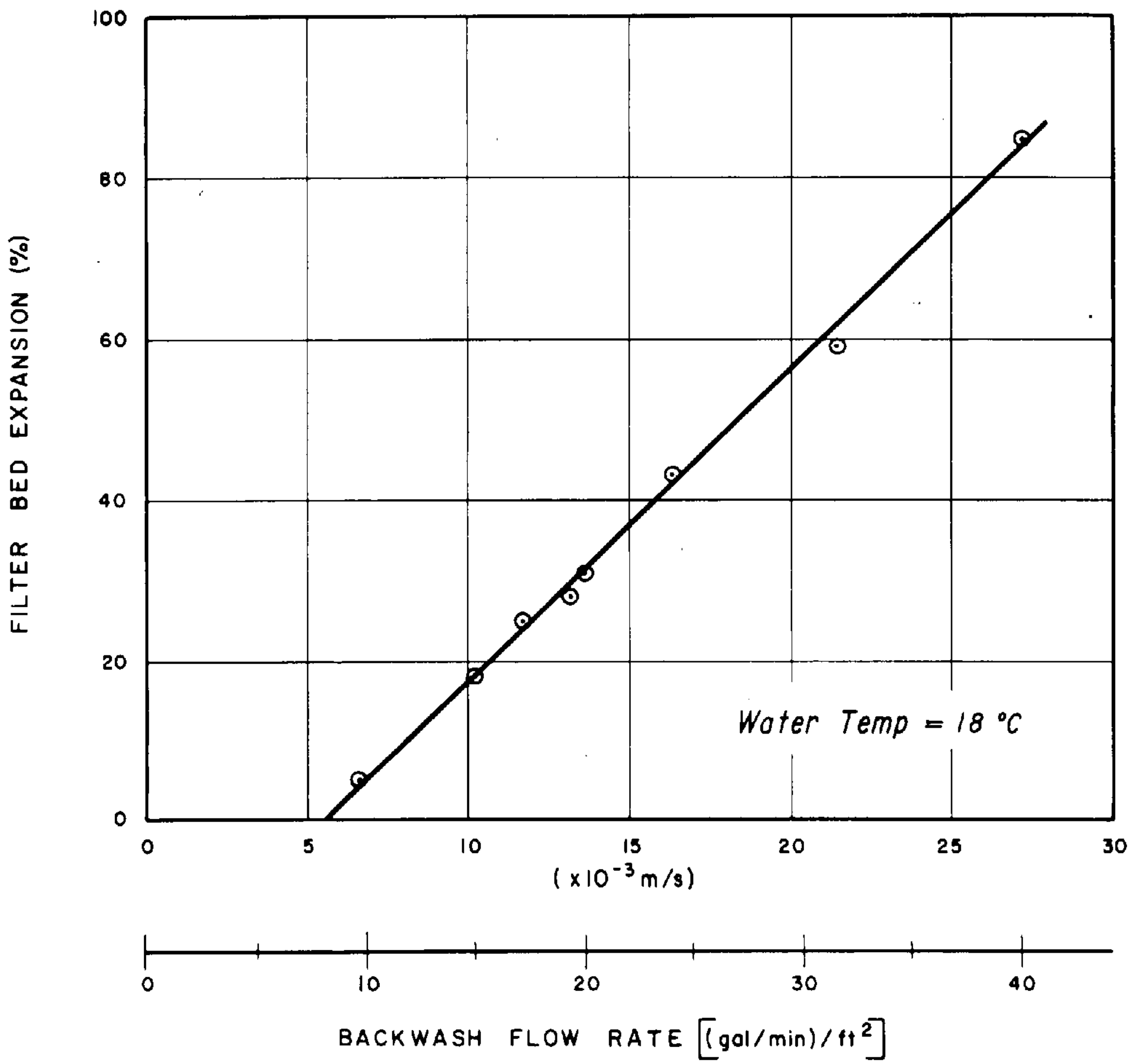

Figure 3.-Filter bed expansion versus backwash flow rate for filter 1.

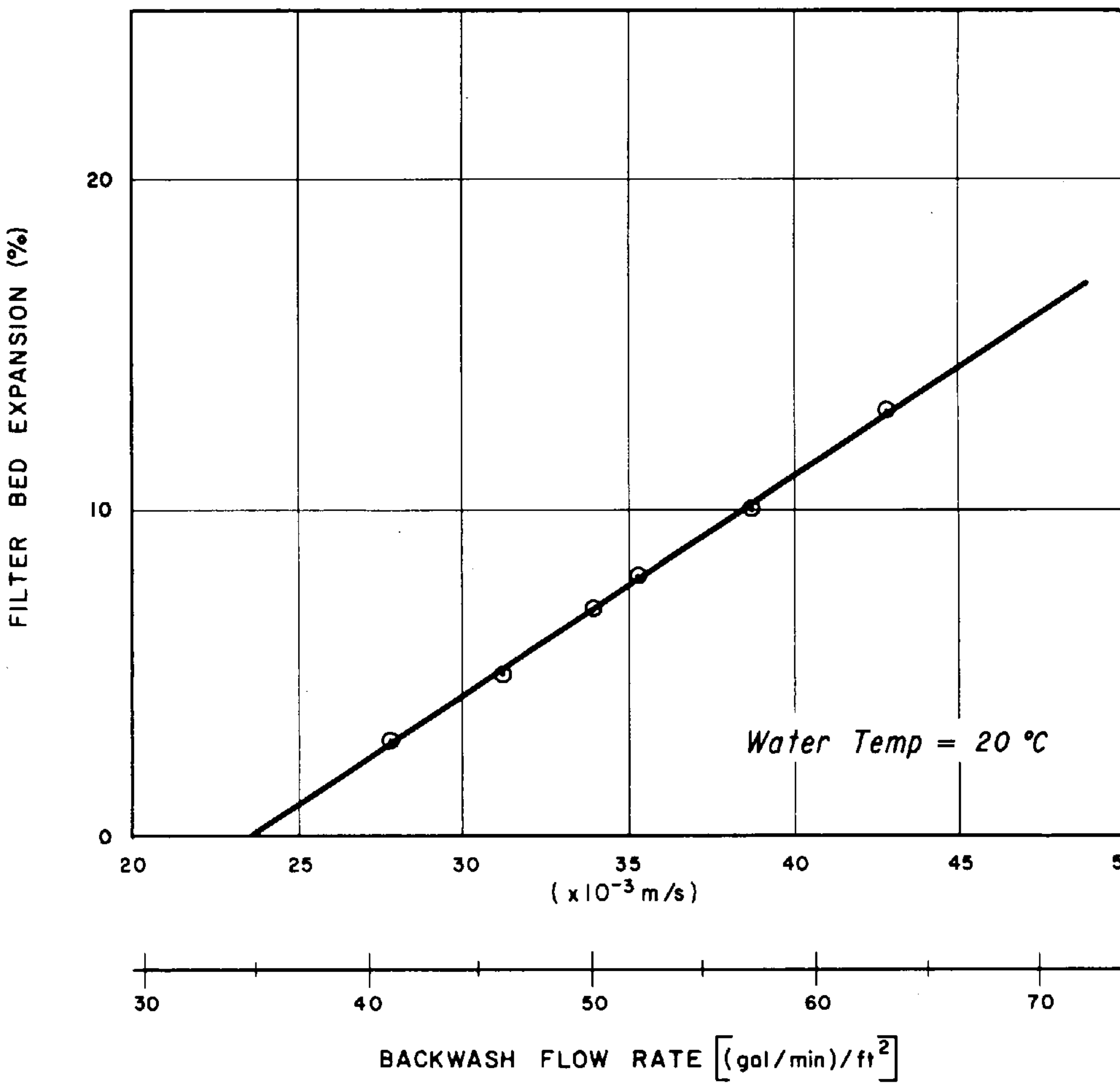

Figure 4.-Filter bed expansion versus backwash flow rate for filter 2.

The fish eggs and larvae were introduced into the filters by adding a small scoop (approximately 70 eggs) every few hours in the distribution and backwash water collection trough.

The plankton net through which the filter effluent passed was examined for eggs and larvae every 15 minutes for 2 hours after backwashing the filter and every 2 hours thereafter. Backwashing was performed during working hours.

The head loss through each filter was recorded every 2 hours during working hours.

EXPERIMENTAL RESULTS

The operation of the filters began on June 16, 1978. A total of approximately 680 hours of operation was logged on each of the filters.

Live eggs and larvae as well as eggs preserved in formaldehyde were added to each filter throughout the experiment. The eggs and larvae were added in identical quantities and simultaneously to each filter. Eggs were also added to that they actually hatched in each filter cell on top of the sand bed.

Tables 1 and 2 are a summary of the eggs and larvae detected in the effluent of each filter throughout the experiment.

These results can be explained as follows. It is surmised that the larvae were small and motile enough to make their way through the void space of the 1.20- to 1.70-mm (0.047-to 0.067-in) size sand even while not backwashing the sand bed. The larvae were not detected in the effluent of filter 1 so that the void space of the 0.425- to 0.500-mm (0.017-to 0.020-in) size sand was small enough to prevent the larvae movement through the bed even while backwashing.

Table 1.-*Filter 1 (0.425 to 0.500 mm (0.017 to 0.020 in) sand)*

Date	Time	Number of eggs detected	Type of eggs	Comments
7-11-78	14:50	3	Preserved smelt*	Eggs detected 5 minutes after backwash
7-12-78	7:30	1	Preserved smelt	After backwash
7-27-78	14:20	2	Preserved smelt	After backwash
8-11-78	8:00	1	Preserved smelt	After backwash

* Rainbow smelt eggs preserved in formaldehyde.

The preserved rainbow smelt eggs that were detected in the effluent of filter 1 proved to have a higher specific gravity and, therefore, a greater settling velocity than the live eggs. An average settling velocity of 914 mm/min (3.00 ft/min) was obtained for the preserved eggs which converts to a backwash rate of 15.2×10^{-3} m/s (22.4 (gal/min)/ft^2). Since a backwash rate of 13.6×10^{-3} m/s (20 (gal/min)/ft^2) was used for filter 1, the rate was not sufficient enough to wash out these preserved eggs. Some of these preserved eggs were small enough and dense enough to make their way through the sand bed voids during backwash. The preserved rainbow smelt eggs were not detected in the filter 2 effluent simply because the backwash was sufficient, 38.7×10^{-3} m/s (57 (gal/min)/ft^2), to wash them out.

Note that during the course of this experiment no live larvae or eggs were detected in either filter effluent.

Table 2.-*Filter 2 (1.20 to 1.70 mm (0.047 to 0.067 in) sand)*

Date	Time	Number of larvae detected	Type of larvae	Comments
6-23-78	17:15	1	Carp	Larva detected while eggs hatching in filter Larva was dead
6-24-78	10:00	2	Carp	Larvae were dead
6-28-78	15:10	1	Carp	Larva detected 5 minutes after backwash Larva was dead
6-28-78	15:15	1	Carp	Larva was dead

Note that only preserved rainbow smelt eggs were detected in the filter 1 effluent while only carp larvae were detected in the filter 2 effluent.

The live carp eggs used in the experiment were clumped or stuck together in groups of approximately 50 eggs or more. These clumps were observed to stay on top of the sand beds since the backwash rate was not sufficient to wash them out. They merely stayed at the top of the sand beds until they broke up and were washed out or until they hatched.

Head loss data were monitored for each filter throughout the experiment. The buildup of head loss through filter 1 was at a rate which required the bed to be backwashed approximately every 24 hours. Figure 5 shows a typical head loss buildup curve versus time for filter 1. The head loss was allowed to increase until the maximum, 1150 mm (45 in), was obtained at which point backwashing was initiated.

The head loss buildup in filter 2 was very slow compared to filter 1. This is a result of the larger void space in filter 2.

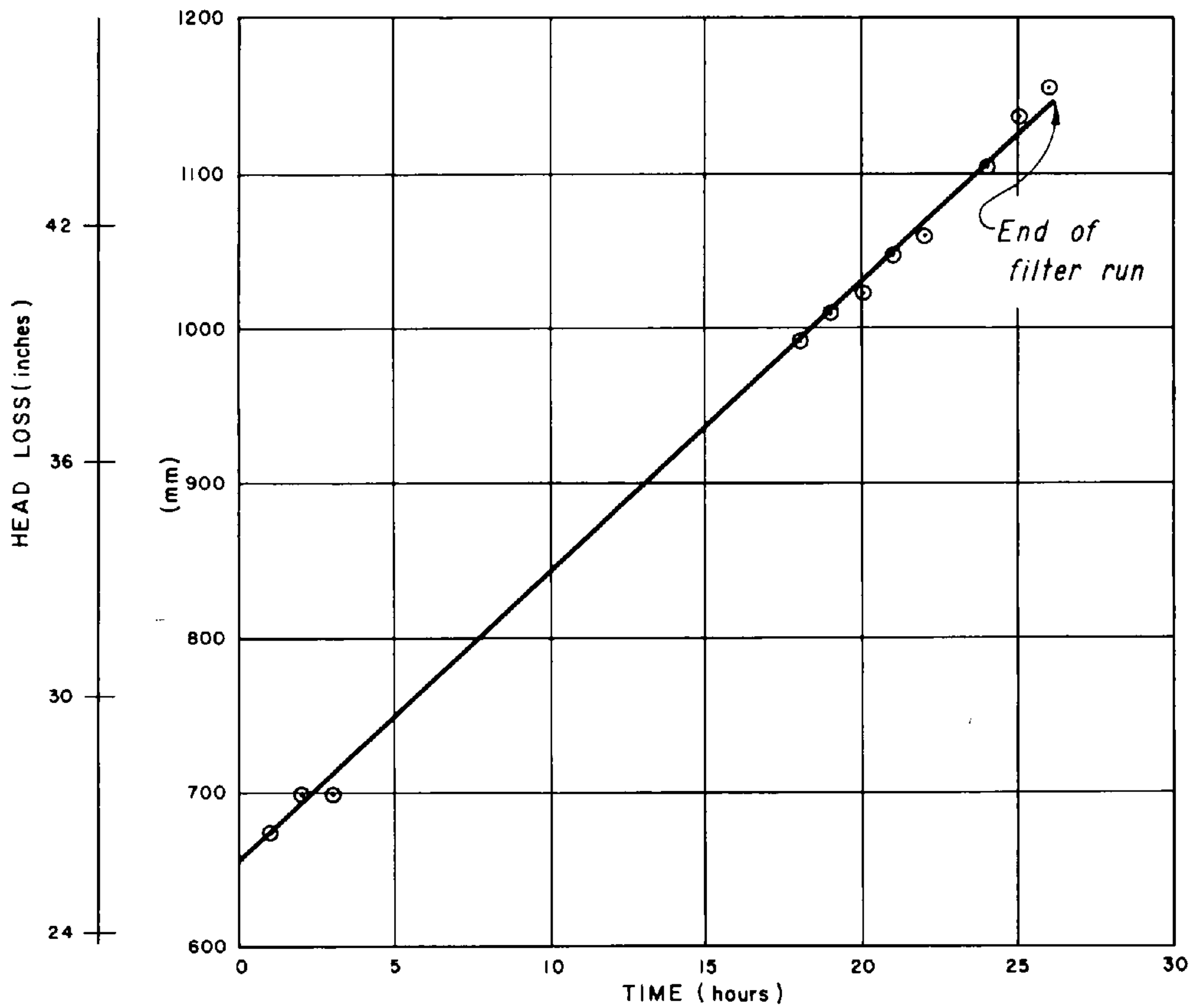

Figure 5.-Head loss versus time for filter 1, June 21, 22, 1978.

The head losses obtained in both filters can be attributed mostly to the amount of solubilized ferrous iron in the laboratory sump water. It is surmised that the ferrous iron in the water was contacted with oxygen as the water cascaded from the distribution and backwash water collection trough onto the water surface above the sand bed (see fig. 2). This contact with oxygen oxidized the ferrous iron to solid ferric hydroxide which was removed in the filters. In the case of filter 2, the void space in the bed was large enough to let most of the ferric hydroxide pass. The ferric hydroxide solid was very evident at the beginning of each filter backwash as large amounts of the reddish brown material were released from the sand.

Near the end of the experiment the laboratory sump was drained and fresh city water was used to fill it. Since none of the soluble ferrous iron was present in this water, the head loss buildup was much slower in the filters. Figure 6 shows the head loss versus time for filter 1 after the water change. Using this water, filter 1 was backwashed every 50 hours. These results stress that the required time between backwashings for a filter is very dependent on the influent water quality. The time can really be determined only by a pilot plant test on the actual water to be filtered.

CONCLUSIONS

1. The motility of fish larvae is the most important consideration when designing a gravity sand bed to prevent the passage of fish eggs and fish larvae. The sand used must be sized and uniformly graded to that the void spaces in the bed will not allow the passage of motile larvae.

2. A sufficient filter backwash rate must be used to wash out large fish eggs and to expand the sand bed enough to allow other suspended solids trapped in the bed to be washed out. But the void space of the expanded bed must not be so great as to allow fish larvae to pass.

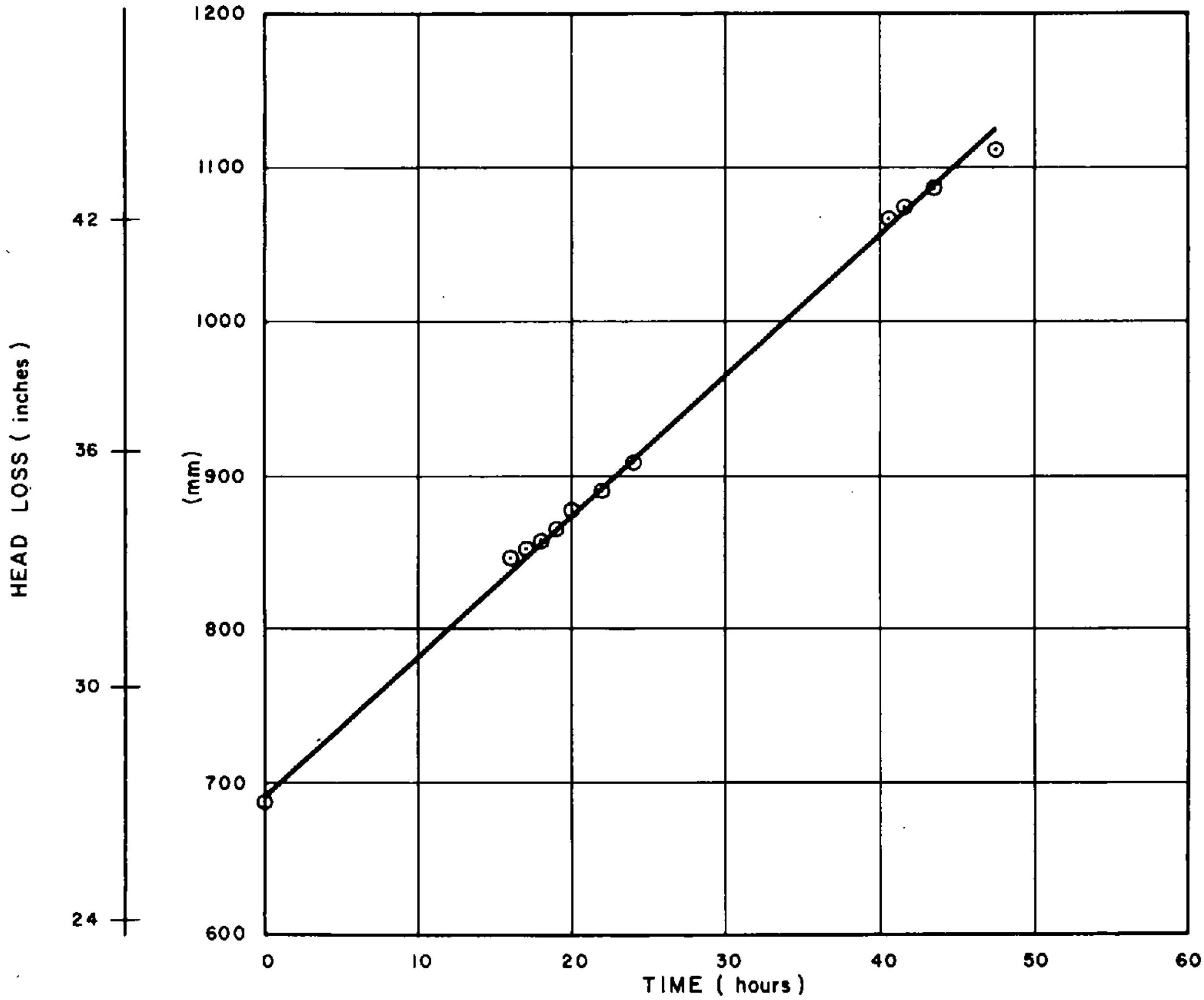

Figure 6.-Head Loss versus time for filter 1, August 8, 9, 10, 1978.

3. It is known that the rate of head loss buildup through a gravity sand filter is a direct function of water quality and filtration rate. Based on the projected water quality to be expected through the Lonetree Reservoir outlet works, a filtration rate of 6.79×10^{-3} m/s (10 (gal/min)/ft^2) is expected to give proper fish egg and fish larvae removal. The time between filter backwashings would be expected to be between 24 and 72 hours.

4. A sand bed using a 380-mm (15-in) depth of 0.425 to 0.500 mm silica sand will remove the eggs and larvae of the common carp (*Cyprinus carpio*) and the rainbow smelt (*Osmerus mordax*). It is expected that this sand bed could remove the eggs and larvae of all of the fish species expected in the flow through the Lonetree Reservoir outlet works. A filter backwash rate sufficient to expand the sand bed 30 percent is considered satisfactory.

The void space in a sand bed of particles sized in the range of 1.20 to 1.70 mm (0.047 to 0.067 in) is large enough to allow fish larvae to pass. Therefore, this size sand is considered unsatisfactory for the purposes of this study.

5. Fish eggs preserved in formaldehyde were shown to have a greater specific gravity than live eggs.

6. The limited tests conducted indicate that high rate gravity sand filters will be totally effective for removing fish eggs and fish larvae from the Lonetree Reservoir outlet works releases if the following procedures are implemented:

a. A filter rinse mode would be required to rinse the sand bed at 6.79×10^{-3} m/s (10 (gal/min)/ft^2) for 10 to 15 minutes after each backwashing. The rinse water and the backwash water would be recycled to Lonetree Reservoir via a holding tank.

b. Only experienced and certified water treatment plant operators would be allowed to operate the filtration plant.

There will always be the remote possibility of an upset in filter operation due to human error occurring at a time when fish eggs or larvae are present. The questions of how fish eggs and larvae would be detected downstream of the filters and what the penalties of such an upset would be must be fully investigated before implementing the full-scale design of the filters.

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