Evaluation Of Crushed Recycled Glass as a Filtration Medium In Slow Sand Filtration

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A program of the **Clean Washington Center (CWC),**

a division of the Pacific Northwest Economic Region

2200 Alaskan Way, Suite 460

Seattle, Washington 98121

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Prepared by

Gray & Osborne, Inc.

701 Dexter Avenue North, Suite 200

Seattle, Washington 98109

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EVALUATION OF CRUSHED RECYCLED GLASS AS FILTRATION MEDIA IN SLOW RATE SAND FILTRATION

CONTENTS

1.0 PURPOSE OF STUDY

The purpose of this study was to evaluate the feasibility of using crushed, recycled glass as a filtration medium in slow sand filters. Slow sand filtration is also referred to as slow rate filtration. Slow sand filters are increasingly being used to treat drinking water in small communities (typically less that 10,000 people) to meet state water quality regulations. This is due primarily to the low costs associated with constructing and maintaining slow sand facilities. Because coagulants or other methods of pretreatment generally are not used in slow sand filtration, slow sand facilities are usually limited to relatively clean water sources with no heavy seasonal algal blooms, and average turbidities below five turbidity units.[1]

The City of Roslyn was selected as a test site, and raw water samples were drawn upstream of the City's municipal water supply reservoir. Raw water characteristics are summarized in Appendix A.

Sand is typically the medium used in direct filtration systems of this type. Consequently, crushed, recycled glass was evaluated concurrently with three other sand media during a pilot project evaluation of slow rate filtration alternatives for the City of Roslyn. The pilot project was conducted to validate the effectiveness of this treatment process for this water source and to generate information to be used in optimizing the design of a full-scale facility.

The evaluation of the crushed, recycled glass was funded by the Recycling Technology Assistance Partnership of the Clean Washington Center (ReTAP), Washington State Department of Community, Trade, and Economic Development.

Caution must be used when applying the conclusions of this pilot project to other water systems. The effectiveness of a filter medium and slow sand filtration treatment of drinking water are site specific such that each filter medium must be evaluated on a case-by-case basis.

[1] Cleasby, John L. "Source Water Quality and Pretreatment Options for Slow Sand Filters," in *Slow Sand Filtration*, American Society of Civil Engineers, 1991.

It is not expected that processed glass will find wide usage in slow sand filtration at any time soon. A typical slow sand filter contains 4000-7000 cubic feet of sand. A facility may have two to six filters. Therefore 10,000-40,000 cubic feet of filtration medium may be contained at one facility. The full amount of filtration medium is purchased for initial start-up, with smaller quantities used for filter renewal on an ongoing basis. It is not currently possible to purchase over 10,000 cubic feet of glass processed to a relatively tight gradation at one time. In addition, it is probably not practical to mix media between filters in a single installation because the difference in specific gravity between glass and natural aggregate may result in variations between the different media filters during backflushing. In addition, if the media were mixed in a single filter, it is likely that the difference in specific gravity would cause the media to stratify over time, with the glass rising to the top.

This study adds to the body of knowledge on glass as a filtration medium. There may be a practical market niche for glass processors in smaller scale single-pass or recirculating water filters.

2.0 BACKGROUND

2.1 STUDY LOCATION

The City of Roslyn is located in Kittitas County in the Cascade Mountain Range of Washington. The City is located approximately 3 miles north of Interstate 90 and approximately 85 miles east of Seattle. The current population is approximately 900 people.

2.2 DESCRIPTION OF EXISTING DRINKING WATER SYSTEM

The source of water for the City's drinking water system is Domarie Creek. The system intake is located approximately 15 miles northwest of the City. A 12 inch, steel transmission line transports water by gravity to the City's concrete, open reservoir. The water is treated by a positive pressure chlorination system prior to entering the 1.0 million gallon (MG) reservoir, from which water enters the distribution system. The City is in the process of installing slow sand filtration technology in accordance with the Washington State Administrative Code (WAC) chapter 246-290.

2.3 REGULATORY MANDATE

Recent updates to the Washington Administrative Code have made filtration mandatory for most water systems using surface water sources. WAC 246-290-630 states that the water purveyor shall install and properly operate water treatment processes to ensure at least 99.9 percent (3 log) removal and/or inactivation of *Giardia lamblia* cysts and at least 99.99 percent (4 log) removal and/or inactivation of viruses. In addition, the WAC states that the purveyor shall treat all surface water sources using one of the following filtration technologies unless another technology is acceptable to the Department of Health (DOH): Conventional, Direct, Diatomaceous Earth, or Slow Sand.

The WAC also requires purveyors to conduct pilot studies for all proposed filtration facilities, except where waived based on engineering justification acceptable to the DOH. The WAC further states that the purveyor shall ensure that the pilot study is (i) conducted to simulate proposed full-scale design conditions and (ii) conducted over a time period that will demonstrate the effectiveness and reliability of the proposed treatment system during changes in seasonal and climatic conditions.

For slow sand filters in particular, WAC 246-290-660 requires that the turbidity of the finished water be less than or equal to 1.0 NTU (nephelometric turbidity unit) in at least 95% of daily measurements made each calendar month, except where waived based on health assessments acceptable to the DOH, and must never exceed 5.0 NTU.

WAC further requires that drinking water meet the maximum contaminant levels (MCLs) presented in 246-290-310, which include upper thresholds for twenty-five inorganic substances. The MCL for total trihalomethanes (TTHM) is 0.10 mg/L calculated on the basis of a running annual average of quarterly samples. MCLs for volatile organic compounds

(VOCs) are to be met in accordance with the Code of Federal Regulations, 40 CFR 141-61(a). Secondary MCLs are specified for color, specific conductivity, and total dissolved solids in WAC 246-290-310. If slow sand filtration is selected, most of these contaminants should be below mandated MCLs prior to treatment.

3.0 SLOW SAND FILTRATION TESTS

Pilot columns were constructed in order to evaluate the effectiveness of slow rate filtration on Domarie Creek surface water.

The City's chlorination system pump draws water directly from the raw water transmission main supplying the reservoir. Un-chlorinated water drawn from the downstream side of the chlorination pump was diverted through the pilot columns for the duration of the project.

Four different filter media were tested in the columns - crushed glass, Steilacoom sand, Trinidad Pit sand, and Ellensburg sand. The media were evaluated in parallel pilot columns. The Trinidad sand is currently used in a slow sand filter at the City of Cashmere's municipal drinking water treatment plant, and the cities of Olga and Snow Creek use a different gradation of the Steilacoom sand at their slow sand filtration facilities.

City personnel in conjunction with Gray & Osborne Inc. constructed and installed the pilot columns, prepared the filter media, and monitored and maintained the pilot project.

3.1 MATERIALS AND APPARATUS

3.1.1 Pilot Columns

A schematic diagram of the pilot columns is provided in Figure 1, Appendix B. The columns were constructed of 15-inch diameter SDR 35 PVC sewer pipe. Each column contained 36 inches of filter medium underlain by several layers of support gravels of increasing coarseness with depth. The succession of filter and support material is shown below:

36 inches	Filter Medium
6-inches	Torpedo Sand
3-inches	Pea Gravel
4-inches	7/8 Inch Gravel
6-inches	1 1/2 Inch Drain Rock

The support media were lowered into the pilot columns in measured lifts and compacted. The filter media were then installed in approximately 6-inch lifts and compacted after every lift.

After installing the filter media, the columns were slowly backfilled with raw water. A 50 mg/L sodium hypochloride disinfectant solution was added to each column. This solution was drawn through the columns until it completely filled the filter media and support gravels. The sodium hypochloride solution was allowed to stand overnight in the columns before starting pilot project testing.

The flow rate to each of the pilot columns was regulated by a rotometer-type direct flow meter. As illustrated in Figure 1, the rotometers were placed on the raw water supply to the columns, thereby controlling the system. An overflow on the distribution header feeding the rotometers provided a constant pressure head to the rotometers. The filtered water stream was discharged at atmospheric pressure above the top of the filter media to avoid emergence of the media and to avoid siphoning. Flows of both raw and filtered water were routed to free fall a short distance so that samples could be collected without disturbing the system.

The columns were located in a heated building located at the City's reservoir site. Even though temperatures were maintained above freezing, it is assumed that the temperature fluctuations experienced by the pilot project were greater than would be experienced in a full-scale facility.

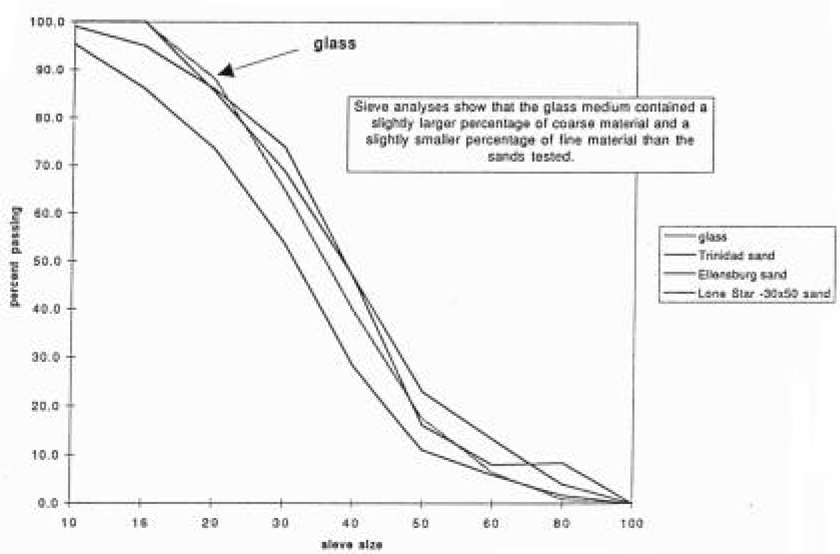
3.1.2 Choice of Filter Media

Filter media for full scale facilities are typically selected based on size characteristics, deliverable cost to site, and availability of adequate quantities for a full-scale facility.[2] These same criteria were used in selecting filter media for the pilot study.

The U.S. EPA's Office of Drinking Water recommends that slow sand filtration media "consist of hard, durable grains free from clay, loam, dirt, and organic matter."[3] The U.S. EPA *Surface Water Treatment Guidance Manual* and the Upper Mississippi River Board of State Public Health & Environmental Managers *Recommended Standards for Public Works (Ten State Standards)* include recommendations for slow sand filtration media size characteristics. The recommendations are that the media have a effective diameter or "d_{10}" (diameter which 10% by weight of the media is smaller than) between 0.35 mm and 0.15 mm, and a uniformity coefficient (U.C.) of 2.5 or less. The uniformity coefficient is the d_{60} (diameter which 60% by weight of the media is smaller than) divided by the d_{10}.

[2] Slow sand filters occupy more space than conventional rapid filters, and typically require tens of thousands of cubic feet of sand.
[3] U.S. EPA, Office of Drinking Water. *Manual of Small Public Water Supply Systems,* C. K. Smoley, 1992.

Table 1 Roslyn Slow Sand Filtration Pilot Project Filter Media Description				
Filter Media	**d_{10}**	**U.C.**	**Passing #200 Sieve**	**Comments**
Crushed, recycled glass	0.26	2.1	0.1%	From Prairie City Recycling, after washing.
Steilacoom sand (8740)	0.25	1.9	0.2%	30 x 50 sand from Lone Star Northwest Steilacoom plant.
Trinidad Pit Sand	0.25	2.5	1.5%	From Dept. of Transportation.
Ellensburg Masonry Sand	0.20	2.4	0.4%	From Ellensburg Cement Products.



The size characteristics of all of the media used for this pilot project fall within the EPA *Guidance Manual* and the *Ten State Standards* recommendations. In addition to these recommended characteristics, past experience has shown that the media should be extremely clean, having less than 0.1% passing the number 200 screen (-200).

Crushed, recycled glass and three sands were tested in the pilot study. A description of each filter medium is provided in Table 1. Chart 1 shows the gradation curves for comparison.

3.1.3 Filter Media Washing

The filter media and support gravels required additional washing in order to remove dirt particles and to meet the desired cleanliness of less than 0.1% passing the number 200 screen. Dirt in filter media and support gravels has caused excessive turbidities in slow sand filters in the past. The washing process has, however, presented significant difficulties in past construction of full-scale facilities.

For the pilot project, washing was done in approximately 8 to 10-gallon batches of media or gravel using a portable electric cement mixer in order to simulate the process of using a cement truck on a full facility scale. The mixer was rotated while a stream of water maintained at approximately 10 gallons per minute was introduced into the drum. A bucket was used to collect media or gravel that washed out of the mixer during the cleaning operation. The washing apparatus was operated for approximately 10 minutes per batch for the filter media and approximately 20 minutes per batch for the support gravels. After washing, water was decanted from the mixer. Any media or gravel collected in the bucket was returned to the mixer. The mixer was operated for a short time in order to homogenize the media or gravel before removal.

3.2 METHOD OF OPERATION

The pilot project was started on February 10, 1994 and operated until March 15, 1995. However, the crushed, recycled glass pilot column was started on August 4, 1994.

The flow rate of raw water to the pilot columns was maintained at a meter reading of 6.0 gallons per hour (gph). This meter reading corresponded to an actual measured flow of 4.0 to 4.7 gallons per hour and a hydraulic loading rate to the filter media between 0.060 and 0.071 gpm/ft^2. Typical loading rates for slow sand filtration range between 0.040 and 0.100 gpm/ft^2. Valves on the rotometers were observed and adjusted as needed Monday through Friday of each week.

The proposed flow rate for a full sized facility is between 0.040 gpm/ft^2 and 0.10 gpm/ft^2. The pilot facility was operated at a flow typical for slow sand filtration. During the pilot project, raw water was fed continuously through the columns regardless of surface water turbidity.

3.2.1 Filter Media Cleaning During Operation

Both scraping and harrowing were tested as methods of cleaning the filters when terminal headloss levels were reached. Scraping is the conventional method of cleaning slow sand filters and basically removes the sand surface. Scraping is done by draining the filter to a water level just below the surface of the sand and removing the dirty filter-cake like material (often termed the "Schmutzdecke") along with the top 1/2 to 1 inch of sand. Harrowing is the process of turning over and mixing the top few inches of sand while slowly backwashing the filter. Backwashing should be kept well below the rate at which the bed becomes fluidized. The water above the filter is decanted as the bed is turned over. Harrowing allows for a significant labor savings over conventional scraping and also shortens the ripening period before the filters can be placed back in use for potable water filtration.

3.2.2 Sample Collection

Table 2 shows the sample collection schedule for the pilot study. Samples indicated as having a "Daily" collection frequency were sampled five days per week (Monday through Friday).

Table 2 Roslyn Slow Sand Pilot Project Sampling Schedule		
Parameter	**Frequency**	**Method**
Raw water turbidity	Daily	Grab samples with portable turbidity meter (HACH 2100p)
Filtered water turbidity	Daily	Grab samples with portable turbidity meter (HACH 2100p)
Headloss across filter	Daily	Differential reading on piezometers
Flowrate	Daily	Rotometer type direct reading flow meter (King 0-12 GPH)
Raw and finished water	Daily	Direct reading with portable thermometer
Total coliforms, fecal coliforms	Weekly	Samples sent to Certified lab
pH	Weekly	Colorimetric
Total Trihalomethanes	Once	Samples sent to Certified lab
Weather conditions & notable	Daily	Operator observations

4.0 TEST PARAMETERS AND RESULTS

4.1 TURBIDITY

Raw and filtered water turbidity samples were collected and measured once a day, five days per week. Samples were analyzed using a HACH 2100P portable turbidimeter. The turbidimeter was calibrated on a regular basis to ensure accuracy.

Figures 2 through 6 in Appendix B show pilot project turbidity results. Figure 2 shows the raw water turbidity determined from the City's daily grab samples. Figures 3-6 show the pilot column effluent turbidity results from the four filter media.

Crushed glass filter medium effluent turbidity appeared to reflect variations in raw water turbidity. Higher effluent turbidity was measured during periods of high raw water turbidity. During December, 1994, the glass filter medium effluent exceeded 1.0 NTU (nephelometric turbidity unit) for more than one day during the month, resulting in an exceedance of the WAC requirement of turbidities less than or equal to 1.0 NTU in at least 95% of the measurements made each month.

In general, the Steilacoom and Trinidad Sands had higher effluent turbidity readings on days experiencing high raw water turbidity than the Ellensburg Sand effluent. The Steilacoom Sand

and the Trinidad Sand both exceeded the WAC turbidity requirement (i.e. turbidities in at least 95% of the measurements made each month less than or equal to 1.0 NTU) on one occasion. The Ellensburg Sand met the WAC turbidity requirement for the entire duration of the pilot project. It should be noted that all the turbidity exceedances were associated with storm events.

The sand filters produced relatively high effluent turbidities during start-up of the pilot project. These high levels are normal during start-up of a slow sand filter and are associated with material shedding from the filter media and support gravels. The Ellensburg Sand had a longer start-up phase with higher turbidity levels than the other filter media tested. This longer start-up phase was assumed to be due to wash-out of small clay particles from the Ellensburg Sand since small clay particles were observed during the initial washing process.

4.2 RATE OF HEADLOSS DEVELOPMENT

The rate of headloss development (pressure drop across the filter) over time is important in determining the practicality of using slow sand filtration. When the filter units reach an unacceptably high (terminal) headloss, they must be cleaned. This terminal headloss is a function of the full-scale facility design. However, published values vary between 1.0m and 1.5m (39 inches to 59 inches) according to the U.S. *EPA Surface Water Treatment Guidance Manual* and are reported as high as to 2.2m (87 inches) according to the AWWA *Manual of Design for Slow Sand Filtration*. The AWWA also states that slow sand filtration performance may be regarded as acceptable if filter runs of at least one month can be achieved before headloss necessitates system cleaning.

Headloss across the filter column was measured using piezometers located above the filter bed and at the base of the filter support gravels.

Figures 7 through 10 in Appendix B compare the headloss versus volume filtered for the four filter media. Dates of cleanings are also shown on the Figures.

The AWWA indicates in its *Manual of Design for Slow Sand Filters*, that slow sand filtration performance may be regarded as acceptable if filter runs of at least one month can be achieved before headloss makes cleaning necessary. However, in order for a slow rate filtration system to be practical for a city or utility, longer filter runs are desirable.

During the pilot project, all four media achieved a minimum of a one month interval before headloss made cleaning necessary. However, the cleaning interval varied greatly both over time and between the four filter media. The Trinidad Sand had the best performance with an average cleaning interval of 6 months. The crushed glass medium required two cleanings over a six month test period. The Ellensburg Sand and the Steilacoom Sand each required three cleanings over a thirteen month test period.

The rate of headloss for the Steilacoom Sand, Ellensburg Sand, and the crushed glass appeared to decrease significantly as the test progressed. This is in contrast to the Trinidad Sand which showed a reduced rate of headloss during the second run.

The crushed glass showed the most significant increase in the rate of headloss over the first and second filter run. This may be due to the method used for filter cleaning. After a filter run of over 3300 ft^3, the filter was harrowed. The subsequent filter run volume was approximately 750 ft^3. Further filter runs would be required to test the effects of harrowing as a cleaning method as compared to scraping and to test the effect of scraping depth on filter run length.

4.3 BACTERIOLOGICAL TESTING

Slow sand filters utilize a combination of biological and physical processes to remove contaminants. Bacteriological testing serves to demonstrate that the filter beds have been adequately "ripened." Ripening is the period initially after start-up or after cleaning before the filter begins to provide adequate removal of pathogens. Past research has shown that these periods can vary from hours to days to weeks depending on raw water conditions (such as temperature).

Bacteriological testing requires documentation of both the source and finished water quality. Bacteriological testing was conducted for two groups of indicator organisms - total coliforms and fecal coliforms. One raw water sample as well as filtered water samples were collected weekly from each pilot column. The raw water samples from the City's transmission line varied from 2 to 300 total coliforms per 100 mL and 0 to 14 fecal coliforms per 100 mL. The method of analysis was Most Probable Number (MPN) as performed by Central Washington University laboratory.

Tables 3 and 4 in Appendix B show the total coliform and fecal coliform test results for the pilot study. The EPA *Surface Water Treatment Guidance Manual* indicates that the removal capability of slow sand filtration is generally appropriate for surface waters with total coliform bacteria concentrations of less than 500 per 100 mL. This is only a generalized capability parameter, actual applicability can be demonstration through the use of a pilot study.

On October 31, 1994, the pilot columns were exposed to highly chlorinated water. This occurred when the transmission line was shut-down for system maintenance but the positive pressure chlorination system continued to operate. Water remaining within the transmission line was continuously recirculated and rechlorinated. The highly chlorinated water was drawn through the pilot columns before the problem was identified and corrected. Even though the volume and the concentration of the chlorinated water drawn through the columns is not known, it is assumed that the biological activity of the filter beds was hindered.

The high coliform counts measured in the pilot column effluent on 11/1/94 are attributed to pilot column chlorination on October 31, 1994, coupled with interruption of the flow in the transmission main and are therefore not shown on figures 11 through 14. The Ellensburg Sand and the Steilacoom Sand pilot columns appear to have been impacted to a lesser degree than the Trinidad Sand and crushed glass columns by exposure to the chlorinated water.

In general, all of the filter media appeared to have similar coliform removal efficiencies. Figures 11 through 14 show the total coliform removal efficiencies (percent removal) for the four filter media when raw water total coliform counts equaled or exceeded 25 per 100 mL. A MPN tube digestion method was used to determine the total coliform levels and levels below 25 per 100 mL were assumed not to be representative of bacterial removal.

4.4 TEMPERATURE AND pH

Temperature and pH are used to determine requirements for disinfection contact time for a full-scale treatment facility and to evaluate potential influences on water quality and corrosivity.

Temperature was measured five days per week and pH was measured weekly. The PH of the Trinidad sand medium ranged between 8.0 to 8.2. The pH was approximately 7.4 for all other raw and treated water samples. Water temperatures varied from 5°C to 15°C.

4.5 DISINFECTION BY-PRODUCTS

Trihalomethanes are a group of chemicals known as disinfection by-products (DBP) since they are primarily formed when specific organic chemicals (trihalomethane precursors) naturally found in water are exposed to chlorine. The concentration of trihalomethanes is usually measured and reported as total trihalomethanes (TTHM).

In addition, the concentration of trihalomethane precursors can also be determined and is often referred to as the measured maximum total trihalomethane formation potential (MTTP). During MTTP analysis, water samples are exposed to high levels of chlorine for an extended period of time. It is assumed that all of the trihalomethanes that can be formed under normal conditions are formed during the extended laboratory incubation period. Without additional treatment, slow sand filtration is not considered an effective treatment method for removing trihalomethane precursors.

MTTP analysis was performed on raw water and glass filter effluent samples collected during the pilot plant operation.

Table 5 summarizes the sample analysis results for MTTP. A raw water sample and a crushed glass filter effluent sample were collected on 10/21/95. Samples were analyzed by the DOH Public Health Laboratories, Seattle, WA.

A comparison of the MTTP concentrations from the two samples indicates that the difference lies within the test method variability. The MTTP value is representative of the maximum potential TTHM concentration. Detailed results are provided in Appendix C.

Because WAC regulations only require that MTTP be sampled on a quarterly basis, these results do not necessarily indicate that this water is in violation of the MCL of 100 μg/L. In addition, other pilot tests have shown that, with certain process modifications, the removal of precursor materials can be enhanced in slow sand filters.[4] The U.S. EPA is collecting data on the use of alternate disinfectants or oxidants, including ozone, chlorine dioxide, chloramines, and UV radiation. While a combined use of disinfectants can effectively reduce TTHMs, these disinfectants will produce other DBPs that are likely to require additional process modifications in the future.[5]

Table 5
MTTP Disinfection By-Product Results

[4] Collins, M. R., and T. T. Eighmy. *Modifications to the Slow Sand Filtration Process for Improved Removals of Trihalomethane Precursors.* American Water Works Research Foundation and American Water Works Association, Denver, 1989.
[5] Clark, Robert M., ed. *Strategies and Technologies for Meeting SDWA Requirements.* Technomic Publishing Co., Inc., Lancaster, 1993.

Collection Date	Raw Water (mg/L)	Crushed Glass (mg/L)
10/21/94	162	212

4.6 METALS AND VOCs

One concern in using the crushed, recycled glass as a filter medium was the unknown potential for undesirable chemical and/or compounds to leach from the glass into the drinking water. In order to evaluate this concern, the effluent from the pilot column containing the crushed, recycled glass was analyzed for metals and volatile organic compounds (VOCs). The raw water source was also analyzed for comparative purposes.

Results from the raw water and glass pilot column effluent analyses for metals and VOCs are included in the Appendix A. All of the metals, inorganic compounds, and VOCs analyzed in both the raw water and the glass pilot column effluent were below the Maximum Contamination Levels (MCLs).

4.7 OVERALL EFFECTIVENESS OF FILTER MEDIA

A specific objective of this pilot project was to evaluate the effectiveness of the crushed, recycled glass as a slow rate filtration filter media. In addition, the effectiveness of the other three sands was also evaluated.

Table 6
Filter Media Comparison

Media	No. of Cleanings Required	Filtered Water Maximum Measured	Met WAC Turbidity Criteria: Yes/No	Average Volume Filtered at 28 inches	Ratio Largest to Smallest Filter Run

		Turbidity (NTU)	(Exceedances)	Headloss (ft^3)	Volume (ft^3)
Crushed Glass	2 in 7.5 weeks	2.45	No (1)	1,731	4.14
Steilacoom Sand	4 in 13 weeks	2.57	No (1)	1,665	4.21
Trinidad Sand	2 in 13 weeks	2.09	No (1)	3,148	1.13
Ellensburg Sand	4 in 13 weeks	1.13	Yes	1,733	4.40

Notes:

1) Test run time for the crushed glass column was approximately 7 1/2 months versus approximately 13 months for the three sand columns.

2) Turbidity maximum and WAC turbidity criteria do not include data obtained one day following transmission main maintenance and column chlorination.

3) Exceedances = the number of months in which the turbidity measurements were greater > 1 NTU in more than 5% of the measurement made each month.

A comparison of the effectiveness of the filter media is presented above, in Table 6.

The crushed, recycled glass and two of the three sands all violated the WAC requirements for turbidity during one month of the pilot project. The Ellensburg Sand never violated WAC requirements and appeared to provide the maximum turbidity removal performance of all the media tested. The Trinidad Sand appeared to provide minimum headloss development. The Trinidad Sand had the largest average volume between cleanings and the lowest ratio of largest to smallest filter run volumes. Each of the filter media appeared to provide similar bacteriological contaminant removal.

4.8 OPERATIONAL PROCEDURES AND FULL SCALE DESIGN CONSIDERATIONS

An important feature of any pilot plant is to test operational methods proposed for use in the full sized facility. For slow sand filtration, the two fundamental operational procedures to test are flow rate and proposed method of cleaning. The pilot columns in this study were operated at a flow rate somewhat higher than would be expected in the full sized facility. In addition, the flow rate was held constant throughout the pilot plant operation. The two methods of cleaning evaluated were scraping and harrowing.

For filter cleaning, both scraping and harrowing were found to be effective as a means of cleaning the filters. However, column headloss appeared to increase more rapidly after the filters were cleaned by harrowing. It is not known if this is the result of the cleaning procedure or variations in the raw water quality.

To allow for harrowing, the final design should have the capability to backflush the slow sand beds at a very low rate with filtered water, and contain piping for decanting the water above the filter. The filters should also be easily accessible to vehicles required to transport large quantities of sand.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The pilot project results suggest that slow rate filtration may be an effective treatment process for the City of Roslyn raw water source with the addition of a roughing filter or other method of pretreatment and/or the capability to divert raw water during high turbidity events.

The crushed glass medium satisfied the gradation characteristics set forth in the EPA *Surface Water Treatment Rule Guidance Manual,* the Great Lakes Upper Mississippi River Board of State Public Health & Environmental Managers *Recommended Standards for Water Works (Ten States Standards),* and the AWWA *Manual of Design for Slow Sand Filtration*.

Maximum contaminant levels for turbidity using the glass sand column were violated for one month of the pilot project, but were otherwise in compliance. The removal of bacteriological contaminants during the pilot study demonstrated that the glass filter media obtained the activity level typically expected during slow rate filtration.

Caution must be used when applying the conclusions of this pilot project to other water systems. The effectiveness of a filter medium and slow rate filtration treatment of drinking water are site specific. Each water system must be evaluated on a case-by-case basis.

The following recommendations should be incorporated into the design of a full-scale facility:

- A full-scale facility should be divided into several filtration cells capable of being independently operated, so that individual cells may be alternately taken off line for cleaning and maintenance purposes.

- A full-scale facility should have the capability of being cleaned by either scraping or harrowing. The facility should have the capability of backwashing the individual filter cells with filtered water and have adequate access for vehicles to transport of large quantities of sand and for harrowing.

- The design of a full-scale facility should include an automatic control valve which will divert flow away from the filter based on a high influent turbidity set-point.

- A pre-treatment process should be considered in order to reduce the impact of high raw water turbidity. The process could consist of sedimentation basins or roughing filters.

- A full-scale facility should include covers to mitigate the potential for algal growth in the filter beds.

It was observed that the rate of headloss development increased over the length of the pilot study for three of the four filter media. It is not known if this trend was the result of changes in the pilot columns cleaning methods or variations in raw water quality. Near the end of the pilot study, the rate of headloss development approached the maximum acceptable limit. For this reason, it is recommended that the pilot plant continue operation as long as possible. It is also recommended that testing be restricted to weekly headloss measurements in order to minimize the expense of continuing the pilot project.

It should be noted that crushed glass typically has a lower density than sands and that as a filter bed, it may fluidize at lower backflow rates than conventional media. Therefore, caution should be used during backfilling or backflushing for harrowing in order to avoid fluidizing the bed and disrupting the structure of the filter beds and support gravels.

In conclusion, results from this pilot project indicate that the crushed recycled glass can act as an effective filter medium for slow rate filtration of some raw water sources. Further testing is warranted for crushed glass to determine long term filter run lengths, maintenance techniques, and particle characteristics of raw versus filtered water.

APPENDIX A

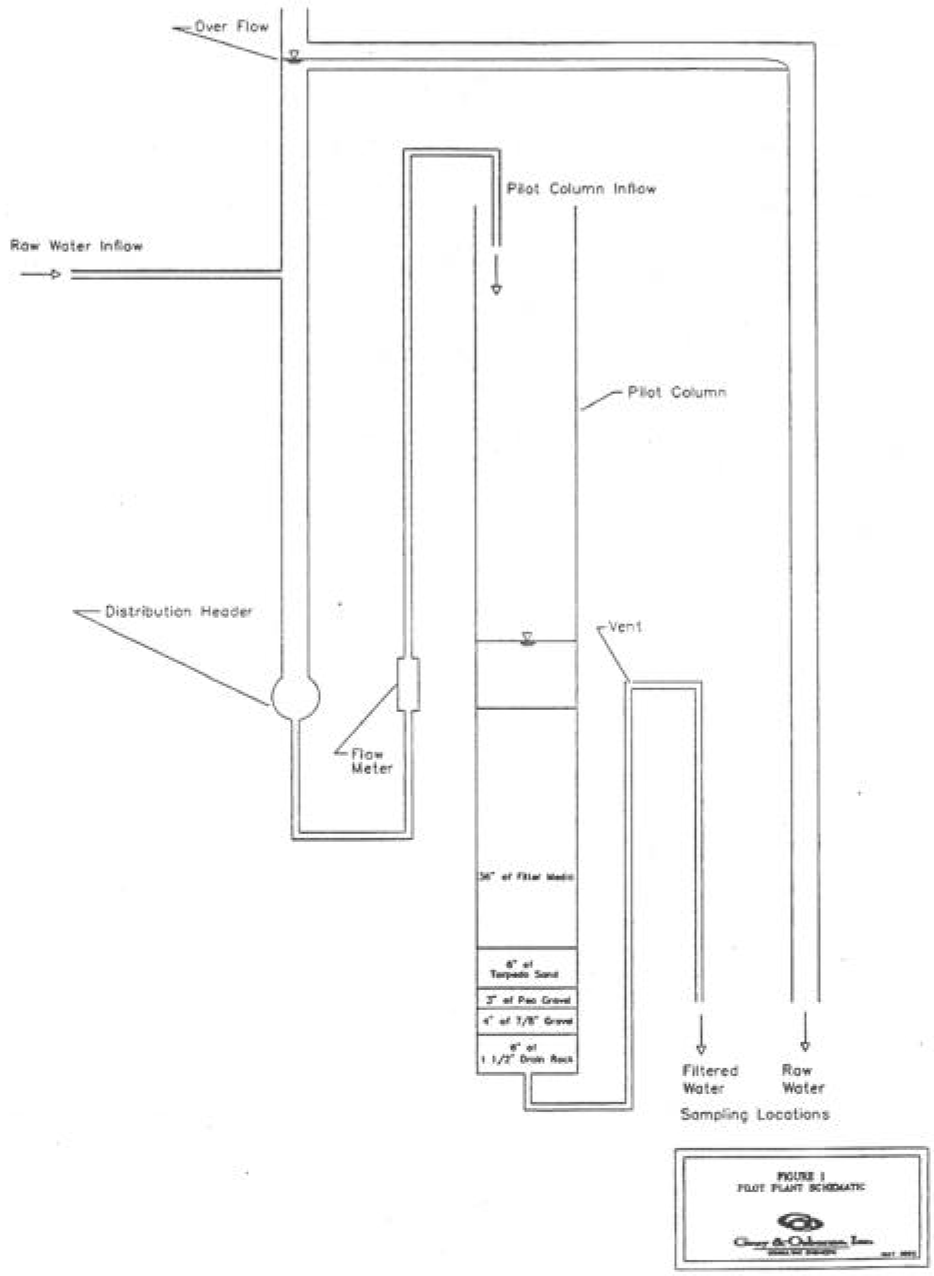
CHEMICAL ANALYSES

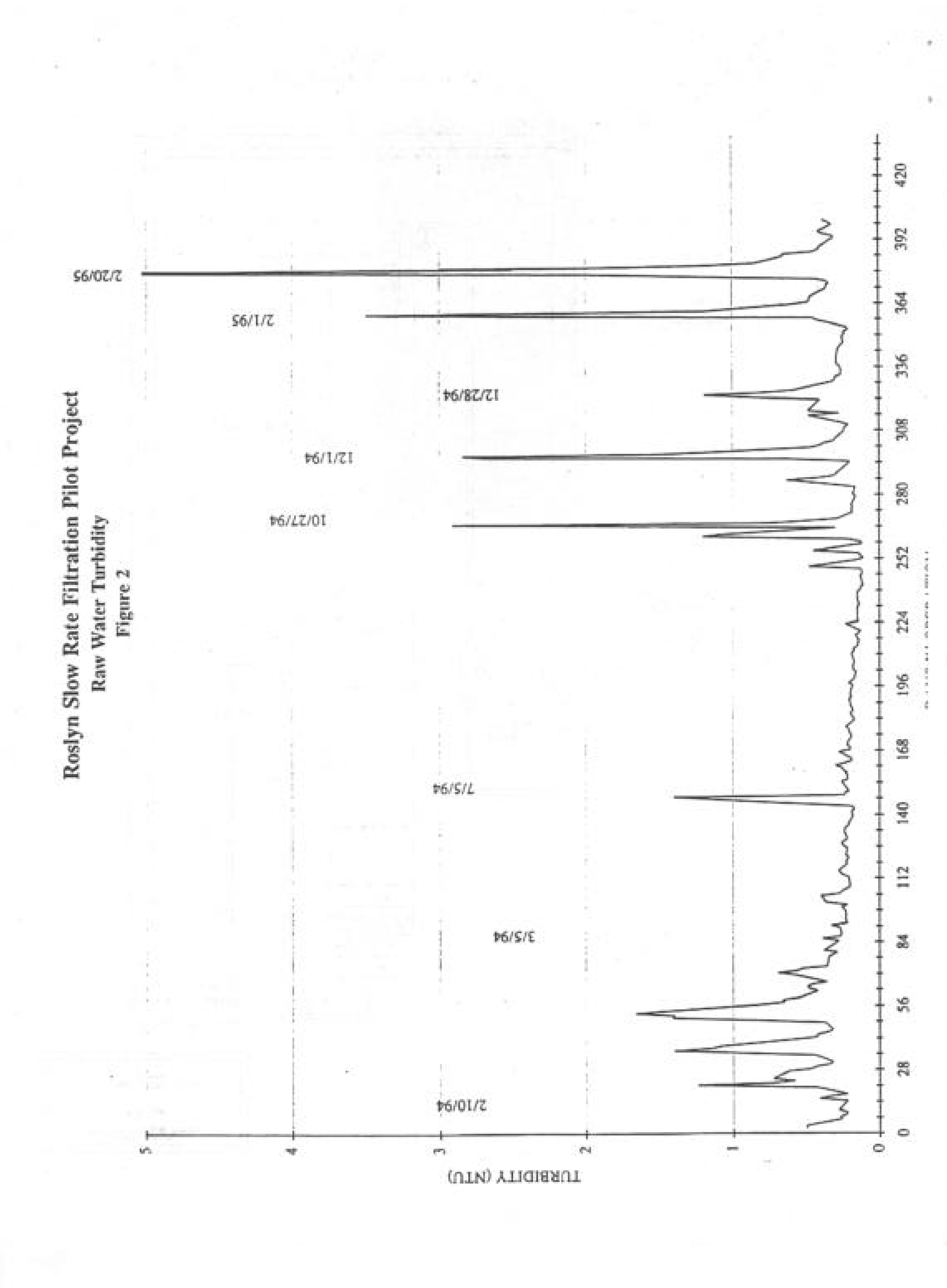
(Not included in this electronic document but available upon request)

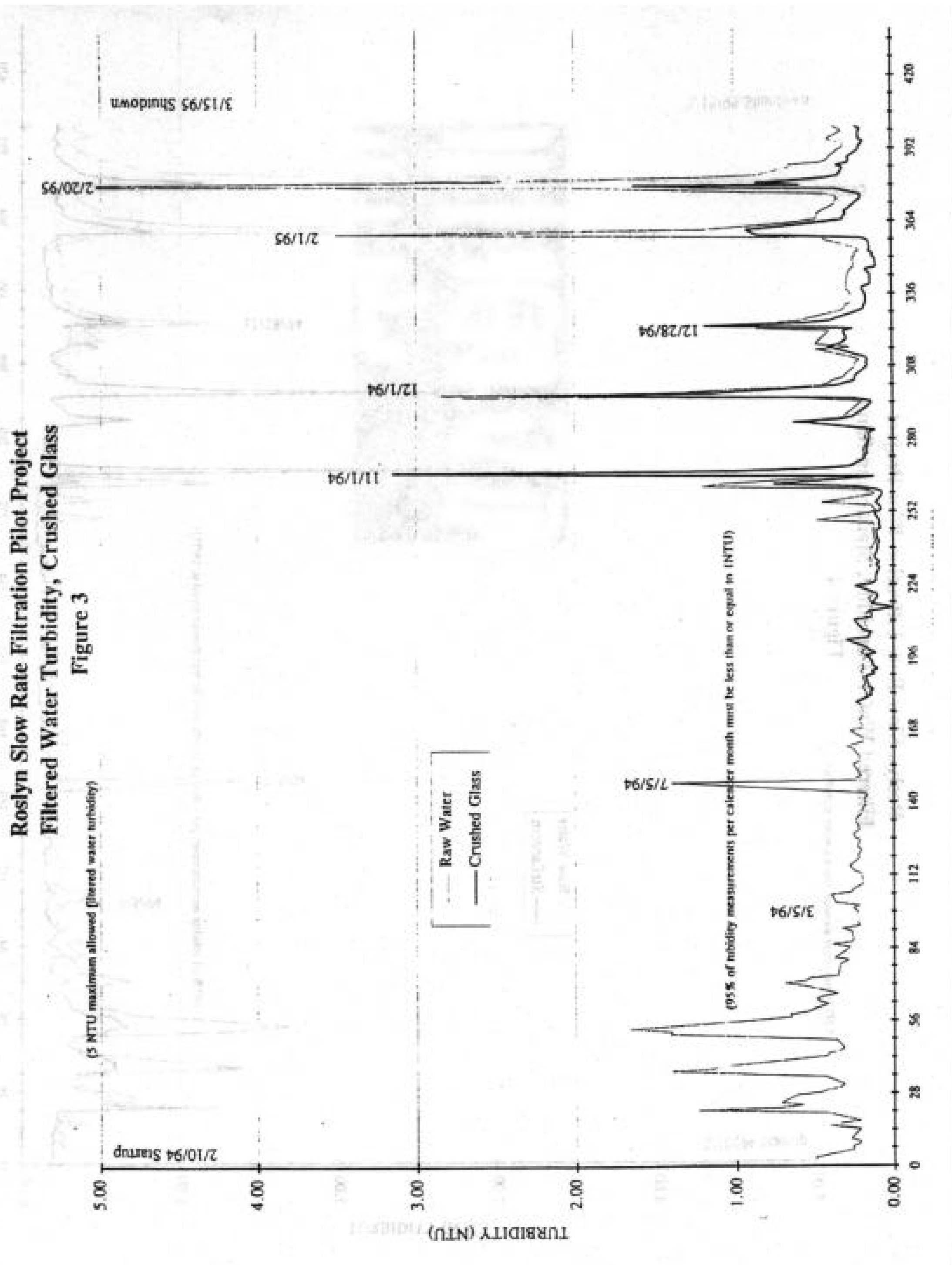
APPENDIX B

SYSTEM DIAGRAM
-
TURBIDITIES
-
HEAD LOSSES
-
COLIFORM REMOVAL EFFICIENCIES

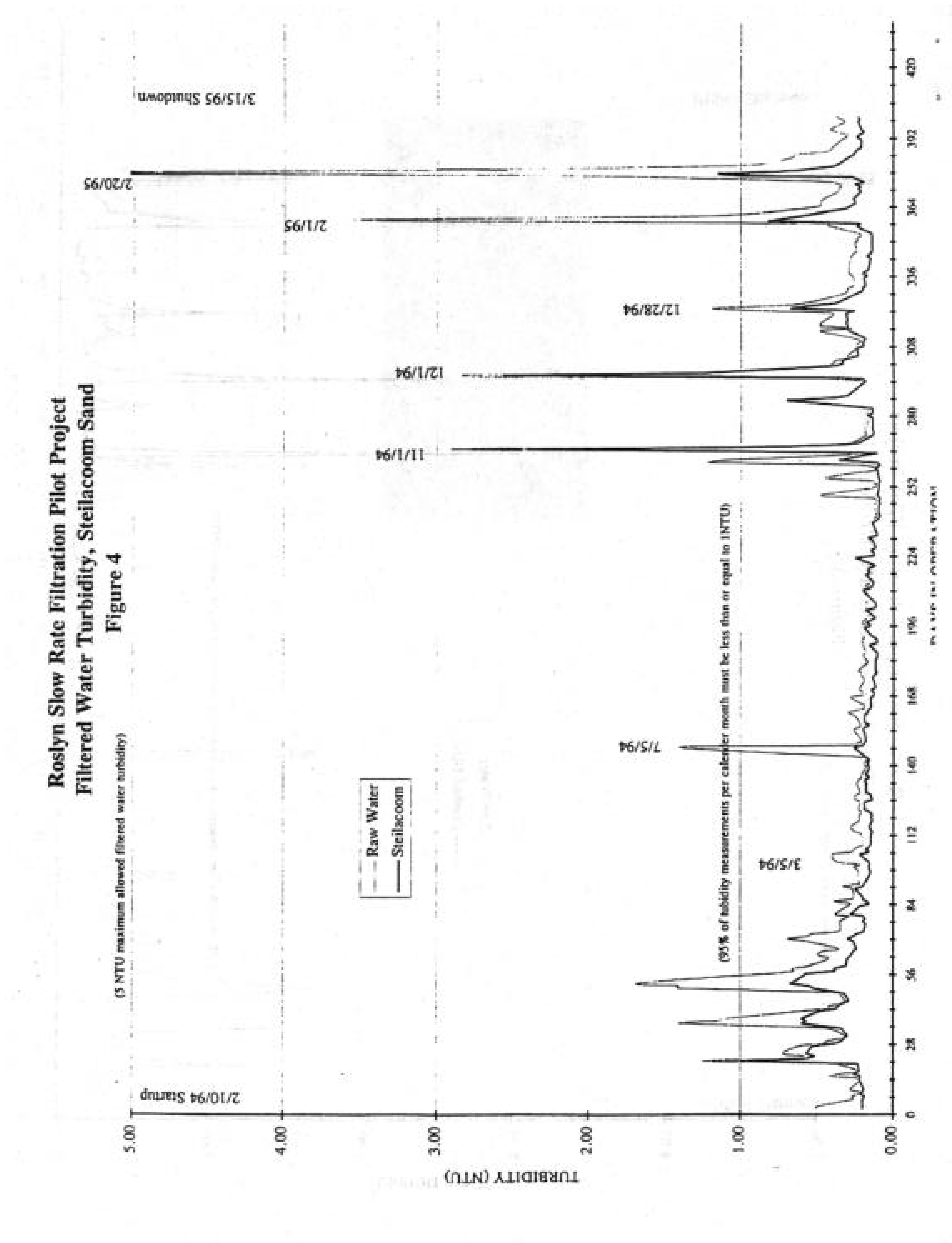
FIGURE 1
PILOT PLANT SCHEMATIC



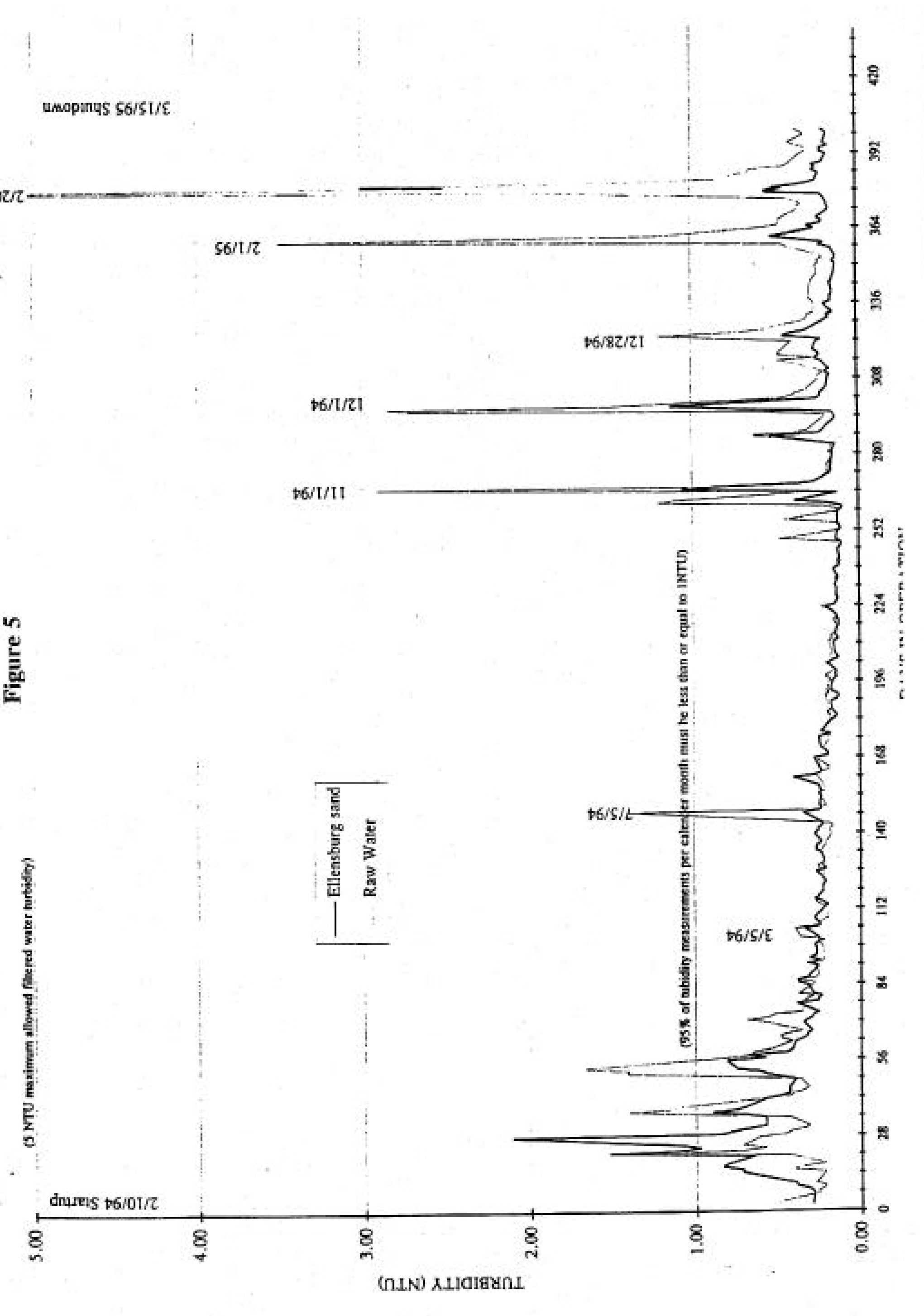

Roslyn Slow Rate Filtration Pilot Project
Raw Water Turbidity
Figure 2
TURBIDITY (NTU)
0
1
2
3
4
5
0
28
56
84
112
140
168
196
224
252
280
308
336
364
392
420
2/10/94
3/5/94
7/5/94
10/27/94
12/1/94
12/28/94
2/1/95
2/20/95



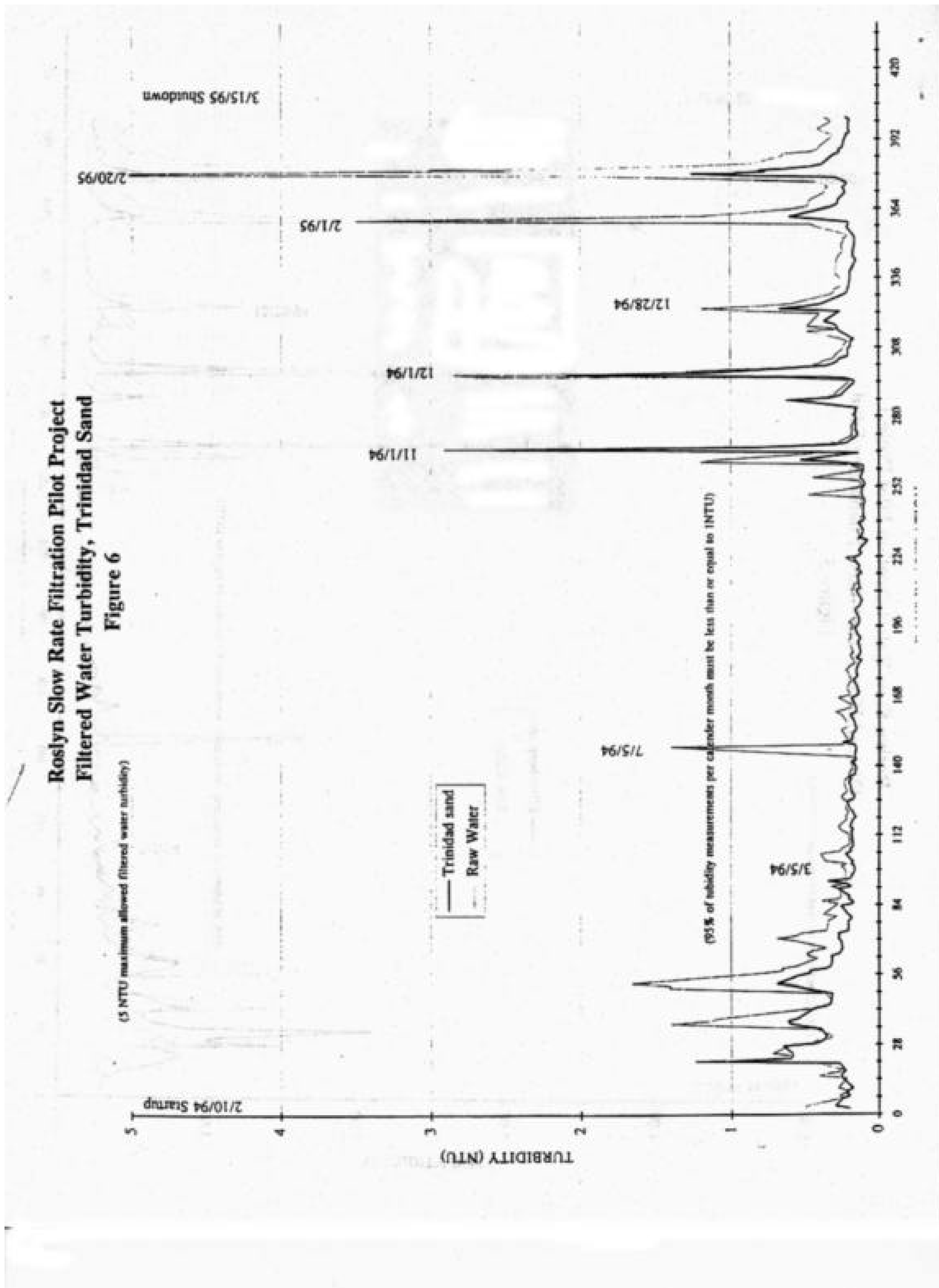
Roslyn Slow Rate Filtration Pilot Project
Filtered Water Turbidity, Crushed Glass
Figure 3



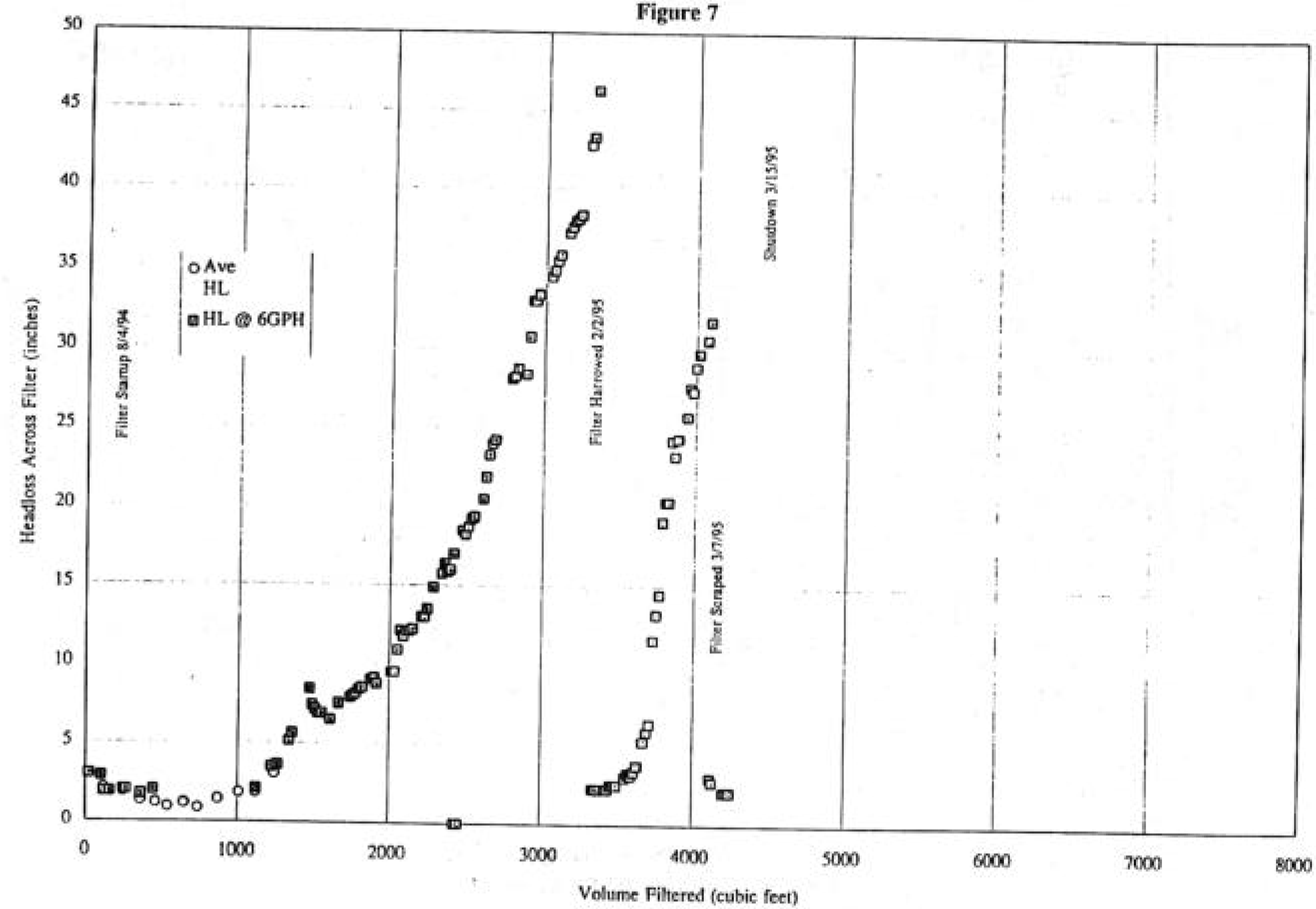
Roslyn Slow Rate Filtration Pilot Project
Filtered Water Turbidity, Steilacoom Sand
Figure 4



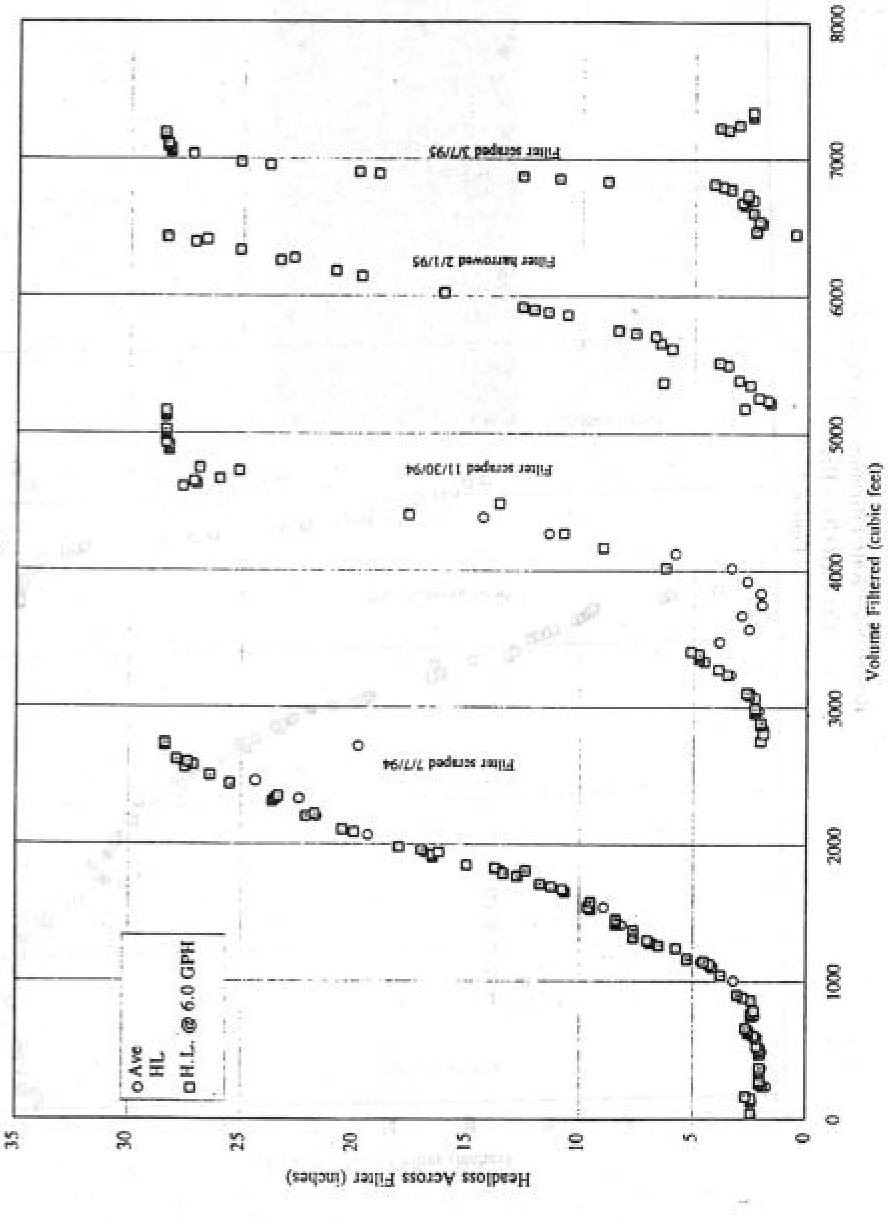
Roslyn Slow Rate Filtration Pilot Project
Filtered Water Turbidity, Ellensburg Sand
Figure 5


Roslyn Slow Rate Filtration Pilot Project
Filtered Water Turbidity, Trinidad Sand
Figure 6
(5 NTU maximum allowed filtered water turbidity)
(95% of turbidity measurements per calendar month must be less than or equal to 1NTU)
Trinidad sand
Raw Water
TURBIDITY (NTU)
2/10/94 Startup
3/5/94
7/5/94
11/1/94
12/1/94
12/28/94
2/1/95
2/20/95
3/15/95 Shutdown
0
1
2
3
4
5
28
56
84
112
140
168
196
224
252
280
308
336
364
392
420

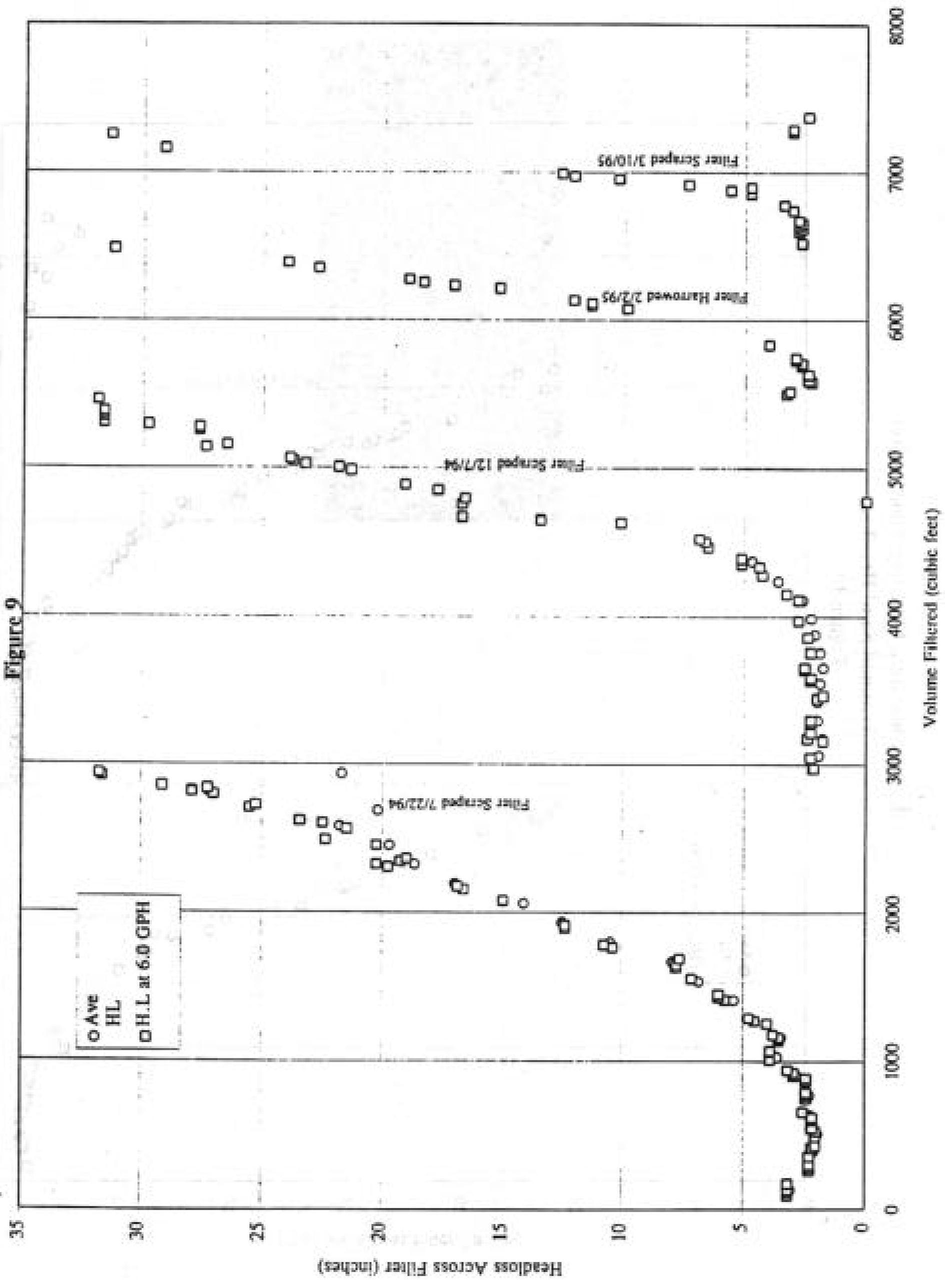
Roslyn Slow Rate Filtration Pilot Project
Crushed Glass Headloss
Figure 7



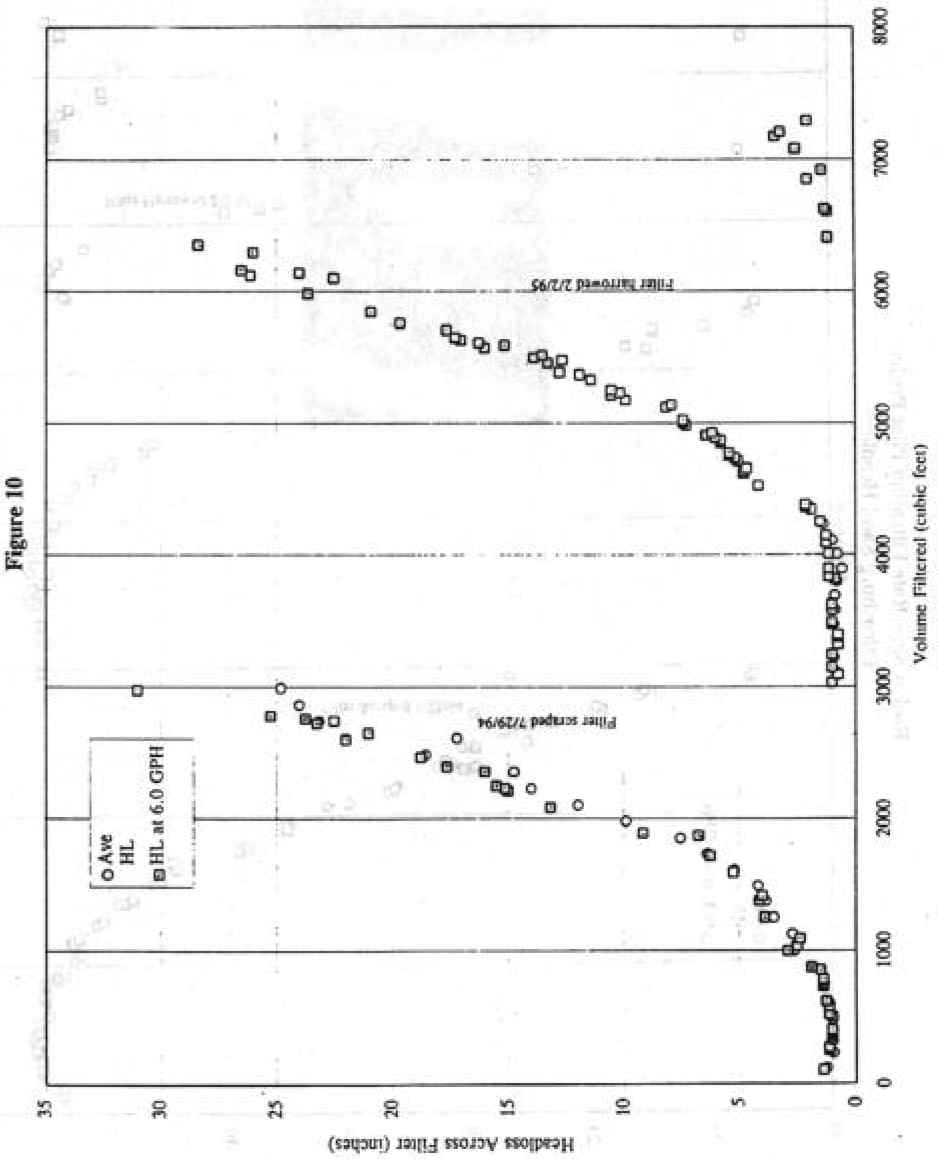
Roslyn Slow Rate Filtration Pilot Project
Steilacoom Sand Headloss
Figure 8



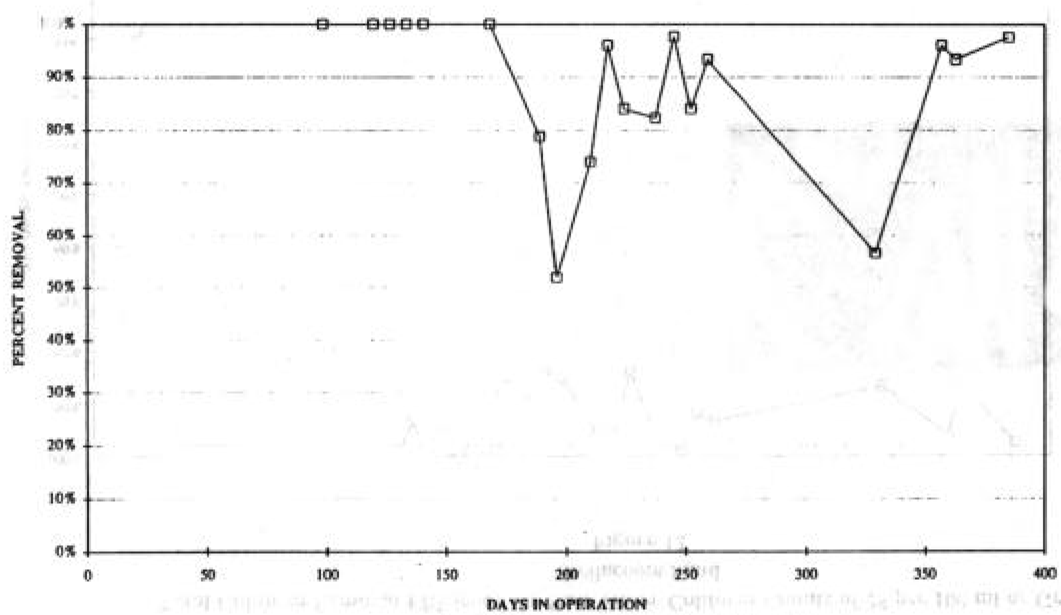
Roslyn Slow Rate Filtration Pilot Project
Ellensburg Sand Headloss
Figure 9



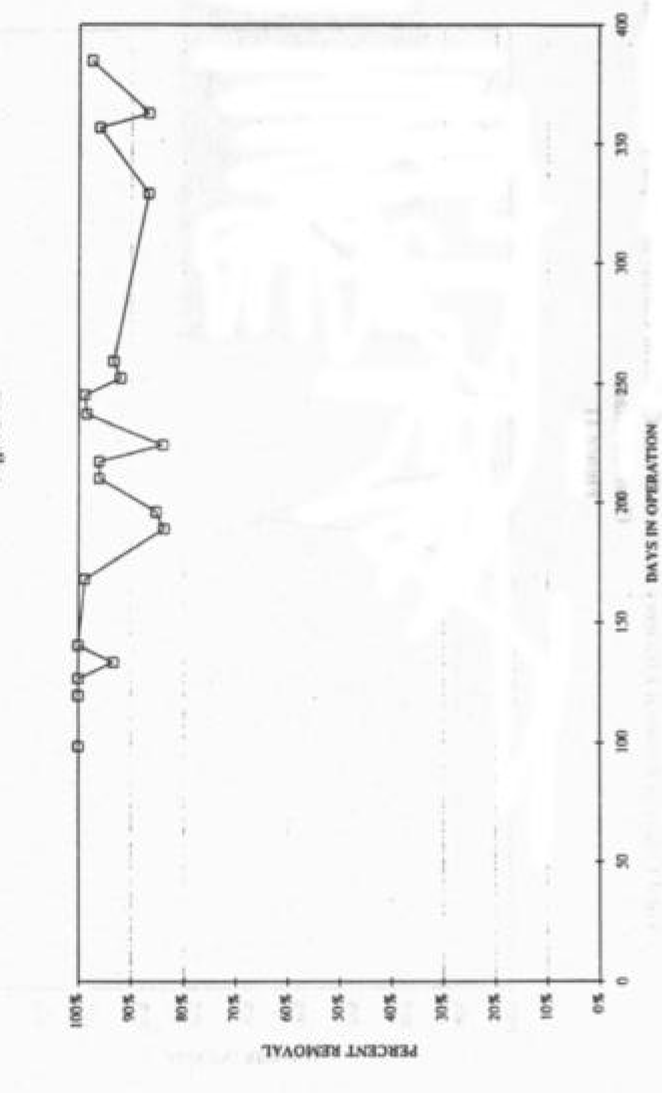
Roslyn Slow Rate Filtration Pilot Project
Trinidad Sand Headloss
Figure 10



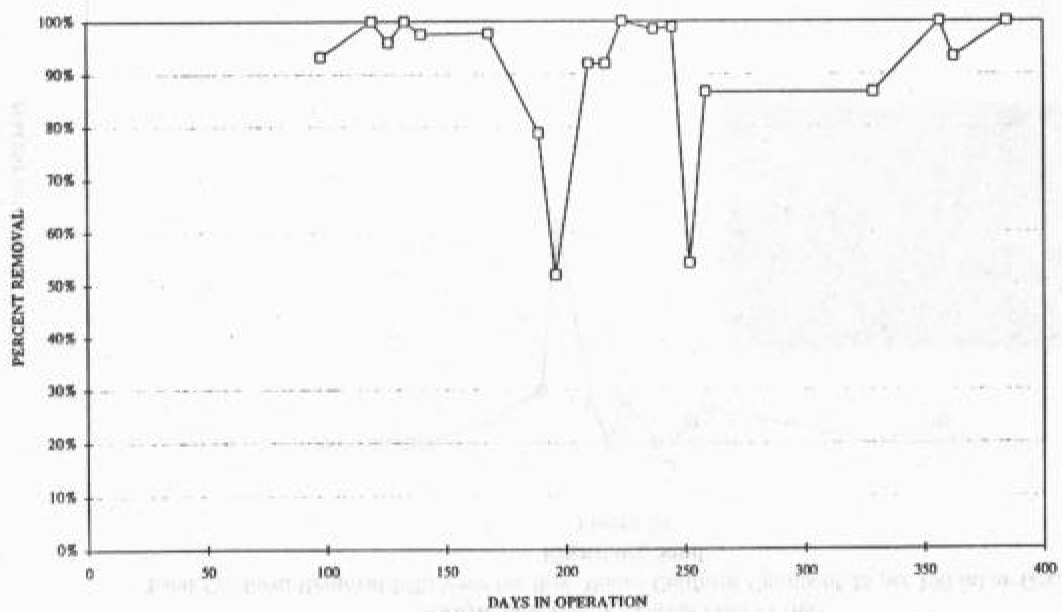
Roslyn Slow Rate Filtration Pilot Project
Total Coliform Removal Efficiency for Raw Water Coliform Counts of 25 per 100 ml or Greater, Crushed Glass
Figure 11



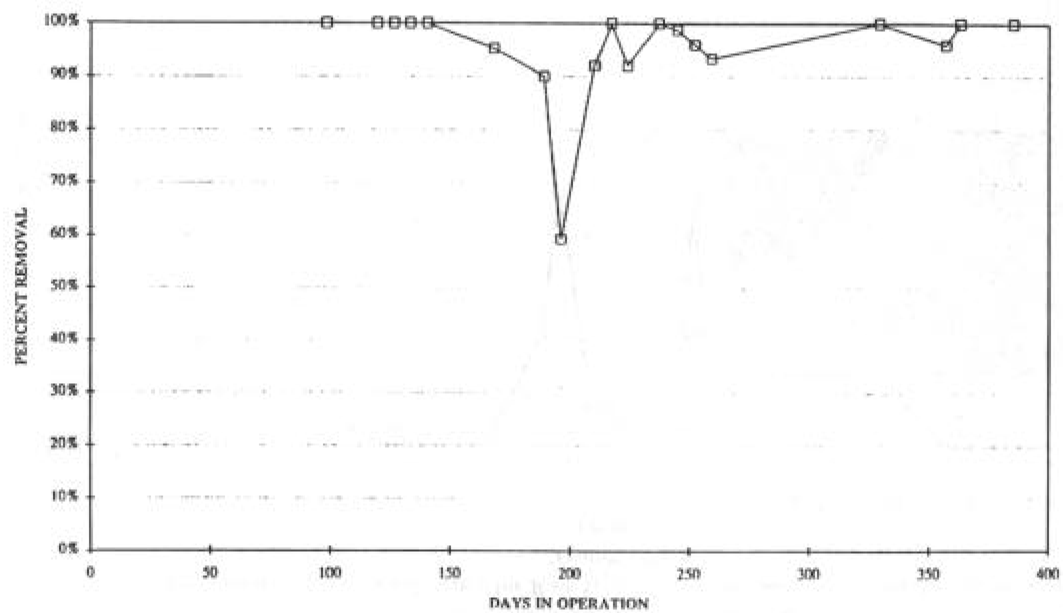
Roslyn Slow Rate Filtration Pilot Project
Total Coliform Removal Efficiency for Raw Water Coliform Counts of 25 per 100 ml or Greater,
Steilacoom Sand
Figure 12



Roslyn Slow Rate Filtration Pilot Project
Total Coliform Removal Efficiency for Raw Water Coliform Counts of 25 per 100 ml or Greater,
Trinidad Sand
Figure 13



Roslyn Slow Rate Filtration Pilot Project
Total Coliform Removal Efficiency for Raw Water Coliform Counts of 25 per 100 ml or Greater,
Ellensburg Sand
Figure 14



APPENDIX C

TRIHALOMETHANES

Washington State Department of Health
PUBLIC HEALTH LABORATORIES
1610 N.E. 150th Street,
Seattle, WA 98155 – (206) 361-2898

Send Report To:	ROSS HATHAWAY / GRAY & OSBORNE 701 DEXTER AVE. N.; SUITE 200 SEATTLE, WA 98109	Lab. Number Date Collected Date Analyzed E.P.A. Method	5409005 10/21/94 11/07/94 524.2

WATER SAMPLE INFORMATION FOR TRIHALOMETHANES

System Name	CITY OF ROSLYN		
System I.D. #	744000	County	KITTITAS
Source #	N/A	Source Type	SURFACE
Specific Loc.	PILOT PLANT - RAW WATER		
Bill To:	GRAY & OSBORNE	#110	Analyst: H. RUARK
	SAME		Data File: 3K07F
			Supv. Initials: [illegible]
			Date of Report: 12-2-94

RESULTS OF CHEMICAL ANALYSIS BY EPA METHOD 524.2

Measurement of Purgeable Organic Compounds in Water by Capillary Column Gas Chromatography/Mass Spectrometry

Monitoring Test : MAXIMUM TOTAL TRIHALOMETHANE POTENTIAL

Regulated Compounds

EPA Code #	Compound Name	* Amount (µg/L)
2941	Chloroform	158.5
2943	Bromodichloromethane	3.6
2944	Chlorodibromomethane	ND
2942	Bromoform	ND
	TOTAL TRIHALOMETHANES	162 ppb

* An amount of ND µg/L indicates that the true concentration is less than the method detection limit of 0.5 µg/L.

11/94

Washington State Department of Health
PUBLIC HEALTH LABORATORIES
1610 N.E. 150th Street,
Seattle, WA 98155 – (206) 361-2898

Send Report To: ROSS HATHAWAY / GRAY & OSBORNE
701 DEXTER AVE. N.; SUITE 200
SEATTLE, WA 98109

Lab. Number	5409006
Date Collected	10/21/94
Date Analyzed	11/07/94
E.P.A. Method	524.2

WATER SAMPLE INFORMATION FOR TRIHALOMETHANES

System Name	CITY OF ROSLYN		
System I.D. #	744000	County	KITTITAS
Source #	N/A	Source Type	SURFACE
Specific Loc.	PILOT PLANT - GLASS FILTER		
Bill To:	GRAY & OSBORNE	#110	Analyst: H. RUARK
	SAME		Data File: 3K07G
			Supv. Initials: [illegible]
			Date of Report: 12-2-94

RESULTS OF CHEMICAL ANALYSIS BY EPA METHOD 524.2
Measurement of Purgeable Organic Compounds in Water by Capillary Column Gas Chromatography/Mass Spectrometry

Monitoring Test : MAXIMUM TOTAL TRIHALOMETHANE POTENTIAL

Regulated Compounds

EPA Code #	Compound Name	* Amount (µg/L)
2941	Chloroform	207.9
2943	Bromodichloromethane	3.8
2944	Chlorodibromomethane	ND
2942	Bromoform	ND
	TOTAL TRIHALOMETHANES	212 ppb

* An amount of ND µg/L indicates that the true concentration is less than the method detection limit of 0.5 µg/L.

11/94