WATER SYSTEM ALTERNATIVES FOR
NEIHART, MONTANA

by

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This paper has been read by each member of the committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

The water supplied to the residents of Neihart Montana has not been treated in accordance with State of Montana standards for potable water. To provide water to meet standards modifications must be made to the current system. Two major criteria must be met by any system modification. First, the distribution system must be protected from freezing, and second, if treated water is discharged to prevent freezing the resulting residual chlorine level in the receiving stream must not exceed standards.

A series of calculations indicate that under the expected range of operating parameters the residual chlorine level in the receiving stream resulting from discharge of chlorinated water will be well under the level assumed to be acceptable.

Possible alternatives for the water supply and/or treatment systems capable of suppling water to meet standards are outlined and construction and operating and maintanence costs for each were prepared. Alternatives presented and construction and operating and maintenance costs for each are, respectively:

Distribution system replacement: $440,000, small;
Pumping loop: $60,900, $1023;
Direct Filtration with Coagulation: $224,300, $25,803;
Diatomecous Earth Filtration: $102,600, $13,290;
Slow Sand Filtration: $125,500, $14,850.

Before any alternative is selected more data must be gathered regarding raw water quality and annual and diurnal variation in water demand.

INTRODUCTION

The people of the community of Neihart Montana have been experiencing a water quality problem. During spring run-off periods water supplied to homes has been in exceedence of maximum contaminant levels for turbidity. Additionally the operation of the system has been such that an acceptable residual chlorine concentration has not been maintained throughout the distribution system. In order to meet State of Montana water quality standards some changes to the water system will have to be made. This paper will suggest several possible additions to and/or changes in the water system that could be made to provide water of acceptable quality.

Surrounded by the Little Belt Mountains, Neihart is located along Highway 89 in a steep and rocky valley at the confluence of Johnston Creek and Belt Creek as shown on the maps below. Great Falls, Montana is 60 miles to the Northeast.

The community began as a mining town, primarly silver and gold mining, but with the demise of mining in the area the town has changed. Currently, most of the residents are retired persons, or part-time residents who use their homes occasionally to enjoy nearby recreational activites such as skiing, snowmobiling, fishing, and hiking. About 100 homes are in Neihart.

Figure 1. Montana Highway Map of the Neihart Area

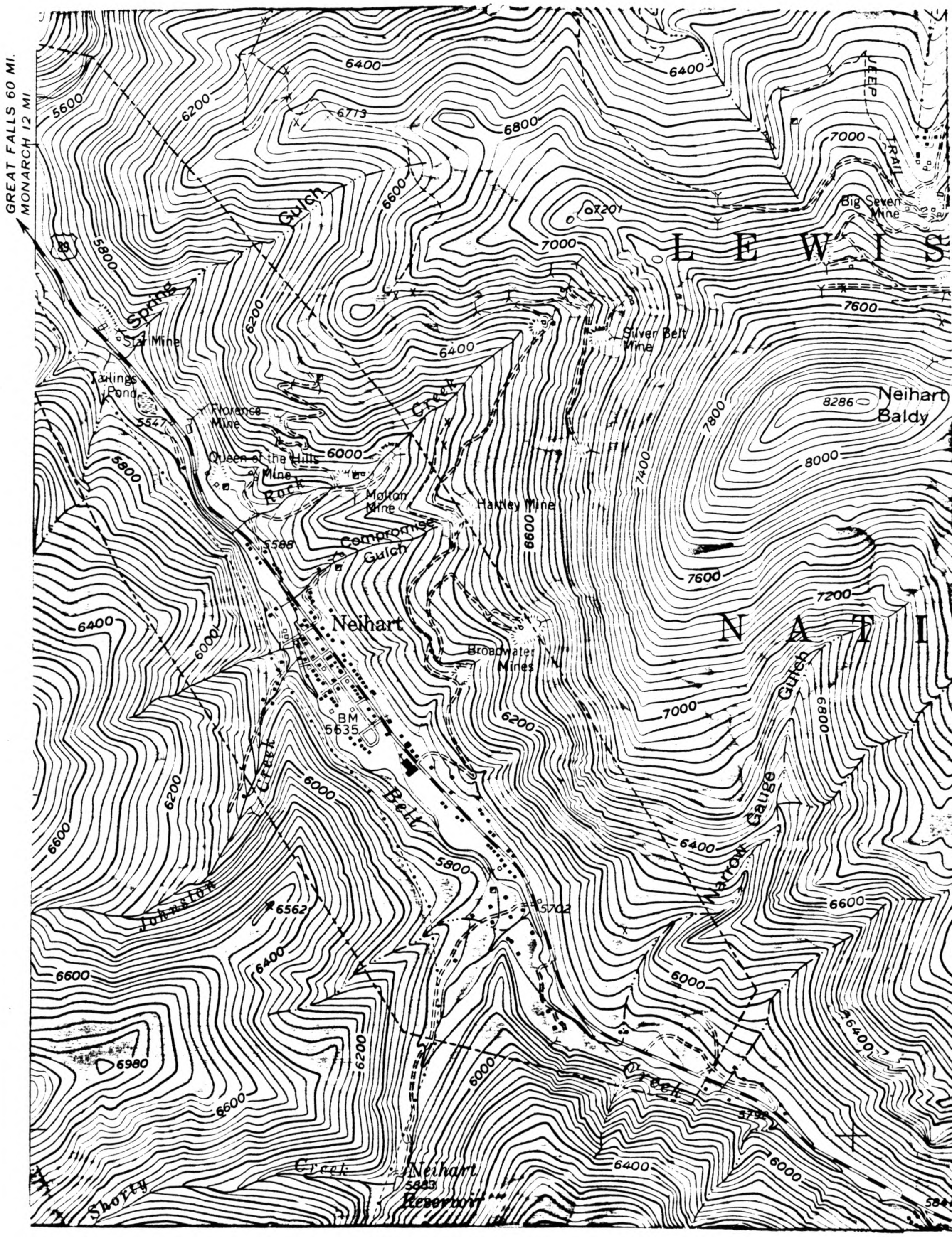

Figure 2. U.S.G.S. Map of the Neihart Area Scale: 2000 ft

Historically, water has been supplied to the town by gravity feed from a Reservoir on O'Brien Creek. Untreated water enters a 12 inch iron pipe from the Reservoir, passes through chlorination, and continues through most of the town. Parts of this system are nearly 100 years old. An unknown amount of water is lost to leakage throughout the distribution system.

In, 1981 John Beer and Associates completed improvements to the water system under a HUD grant to develop a secondary water source. Black Chief Spring, located on the valley wall on the east side of town was developed, a 100,000 gallon Reservoir was installed, and the spring water supply was hooked into the existing system at the main. Water from Black Chief Spring has been approved for use without treatment. The system as it exists today is shown diagrammatically in Figure 3.

The major problem with the existing distribution system is only evident during the winter, when freezing temperatures are prevalent. In several locations the water lines are only 2 feet below the ground surface, therefore parts of the system are prone to freezing. The Black Chief Reservoir, an above ground steel tank, also has a problem with freezing. Freezing has been prevented by opening the system during cold periods to allow water to run freely through the system. This water drains into Belt Creek.

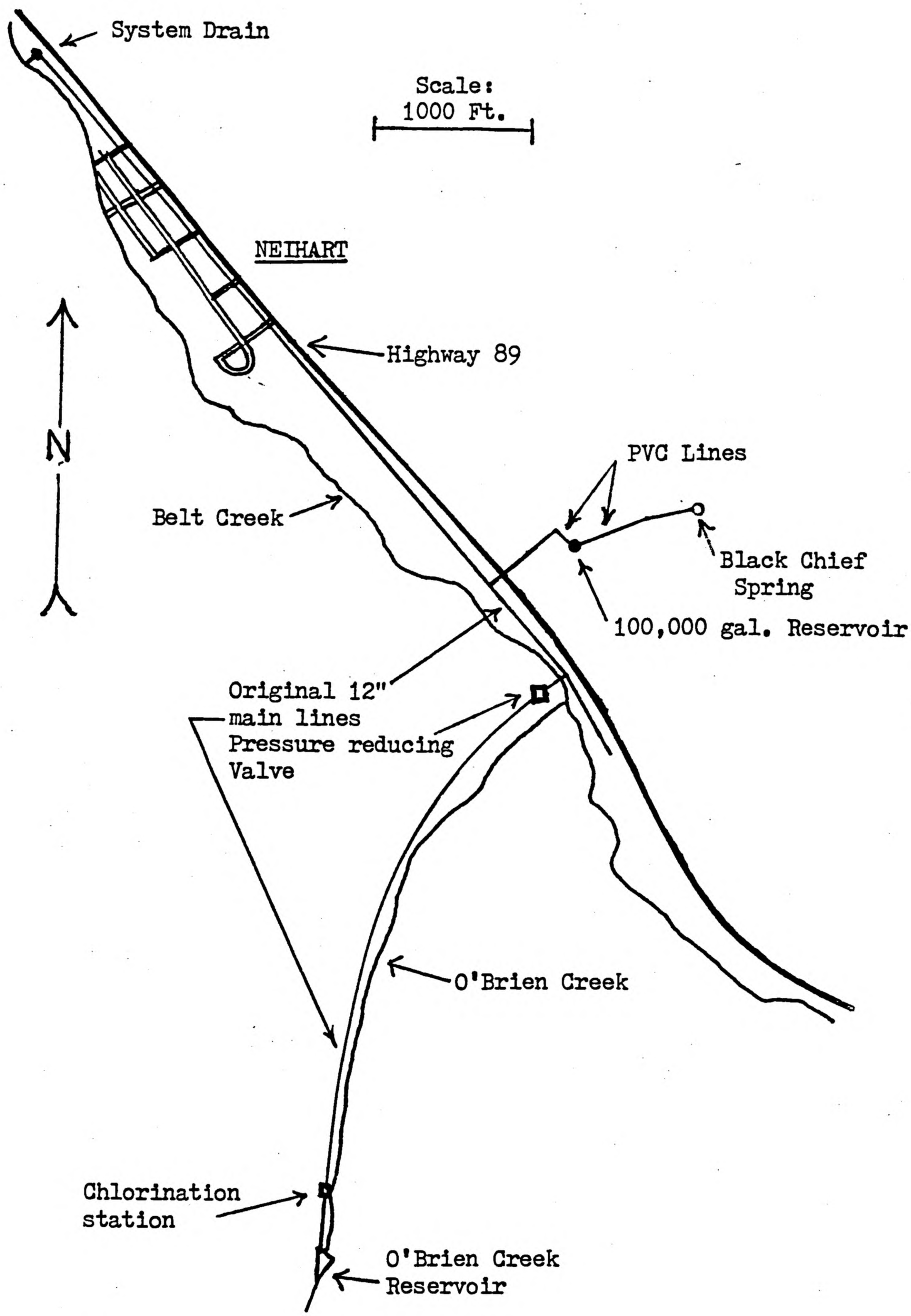

Figure 3. Neihart, MT water system

Black Chief Spring can provide water in the range of 80 to 100 gpm throughout the year. While this quantity is sufficient for consumptive use in a community the size of Niehart, it is not enough when water is allowed to run to prevent freezing.

Current operation of the system utilizes Black Chief spring water during periods when there is no danger of freezing, serving all but about 15 homes, which are located along O'Brien Creek at elevations above the Black Chief Reservoir. With the possibility of freezing present, the pressure reducing valve and the system drain valve are opened to allow the necessary chlorinated water from O'Brien Creek to flow through the system. During warm periods the pressure reducing valve prevents flow of O'Brien Creek water into Black Chief Reservoir. Chlorinated water is supplied to those 15 homes along O'Brien Creek throughout the year from the O'Brien Creek Reservoir.

According to State standards the surface water supplied from the O'Brien Creek Reservoir must be treated in a manner that will inactivate or remove Giardia cysts. This can be accomplished by filtration followed by chlorination or by chlorination with sufficient contact time to inactivate the cysts. Current chlorination practices at Neihart do not protect against Giardia contamination. When the O'Brien Creek source is in use, the contact time and chlorine dosage in the system are not adequate to insure inactivation.

The water that is wasted to Belt Creek during the winter contains chlorine. State standards for waste water treatment plant effluent receiving streams require the resulting residual chlorine concentration be under 0.05 mg/l at the point the water is discharged into the stream. The acceptable chlorine level is dependent on the individual stream, and is specified in the discharge permit issued for the stream. An intensive survey suggested maximum residual chlorine levels of 0.002 mg/l in waters where trout and salmon are present (Brungs, 1973). The residual chlorine concentration equals the sum of the fixed available chlorine (FAC) and combined available chlorine (CAC) concentrations. Neihart may be exceeding standards under normal winter operations when discharging potable water to Belt Creek.

The above sets forth the framework of the water problem which is summarized here:

1) Water which meets State of Montana standards must be supplied to the residents of Neihart.

2) The water system must be protected against freezing.

3) Surface water supplies must be treated as if Giardia were present.

4) If water is discharged into Belt Creek, the residual chlorine concentration in Belt Creek at the point of mixing may not exceed 0.05 mg/l.

5) The people of Neihart must approve of the proposed solution to their water problem.

Cost Estimates

Cost estimates are given for each of the alternatives to follow. Cost estimates will be valuable in comparing costs of systems and in assessing the magnitude of required capital cost. The costs for each system are divided into a construction cost and a yearly operating and maintenance cost. Construction costs include all items except engineering, contractor profit, land purchase, interest during construction, and special site work. When applicable, construction costs are updated to September, 1986 using the Engineering News-Record Construction Cost Index. Construction Costs can be expected to be within 45% (Montgomery, 1985).

Operating and maintenance costs include labor, electrical energy, and maintenance materials. Costs of treatment chemicals such as chlorine and coagulants are not included in the operating and maintenance cost. Labor cost is calculated at $8.00/hr. and electrical energy $0.045/kw-hr. Maintenance material cost is updated using the U.S. Department of Commerce Producer Price Index to Sept, 1986.

PROBLEM SOLUTIONS

Possible treatment and distribution systems to meet the above criteria may be divided into two categories: systems that discharge water into Belt Creek to prevent freezing and systems that do not discharge into Belt Creek. The systems that do not discharge into Belt Creek will be protected from freezing by some other method. These systems will be considered first.

Non-Discharge Systems

Non-discharge systems must be protected from freezing by some method other than allowing O'Brien Creek water to flow freely through the system. Therefore these systems will use only Black Chief Spring water, without treatment.

Distribution System Replacement

The most obvious method to protect against freezing is replacing and burying the distribution lines below the frost depth throughout the town. This solution has been proposed and detailed by an engineering firm.

Replacing and properly covering the lines was considered a good solution for the following reasons.

1) No water would be discharged into Belt Creek.

2) New lines to homes would allow the installation of water meters and curb valves at each home. Metered water at a high enough cost may prevent residents from running

water throughout the winter. The curb valve would allow the water to be shut of at the main, below frost line, to unattended houses.

3) The system would be nearly maintenance free.

4) There would be no treatment cost associated with the water.

5) Black Chief Spring would be an adequate source of water, if no water is wasted.

The people of Neihart rejected this proposal for several reasons including:

1) The inconvenience involved in replacing the old lines was prohibitive.

2) Individual customers would have had to replace lines from their homes to the main line at their own expense.

3) Homes on O'Brien Creek at elevations above the Black Chief Reservoir would not have been served by the new system.

4) It was uncertain that Black Chief Spring would have provided an adequate supply of water during years of less than average rainfall or in the winter, as many part-time residents leave the water running to prevent freezing when their homes are unheated.

5) The project had a very high cost; about $440,000, not including the cost of lines from the main to residences.

6) The water supplied from Black Chief Spring is highly aerated and is objectionable to some residents.

Because this proposal has been rejected it will not be considered further.

<u>Pumping Loop</u>

It may also be possible to prevent freezing of the main lines by constructing a pumping loop (see Figure 4). Water may be pumped from the system at the system drain and lifted to the main line just below the O'Brien Creek Reservoir at a rate sufficent to prevent freezing. Summer operation would pump water at a rate sufficent to provide an adequate supply of water to the O'Brien Creek residences. This system has advantages and disadvantages as follows.

Advantages:

1) Only the inexpensive, untreated Black Chief water would be supplied to all homes, including those on O'Brien Creek.

2) No water would be discharged to Belt Creek.

3) Existing water lines would not need to be replaced.

4) The new line would not need to be buried below frost depth, although burying the line below frost depth may be advantageous.

Disadvantages:

1) The pump loop system would have associated pumping and maintenance costs.

2) As with the first system proposed, Black Chief spring may not be an adequate supply because of leaks in the existing system and because water is left running in some homes.

3) Residences on O'Brien Creek at elevations above the Black Chief reservior would not have water available at a rate higher than the pumping rate for fire fighting, should the need arise.

Figure 4 shows the existing water system and the proposed pumping loop. Water would be taken from the system drain and freely discharged into the old 12 in. main line just below the O'Brien Creek Reservoir. The new line could be routed along the power line that passes the town on the west side of Belt Creek and proceeds up O'Brien Creek. A pump could be located at any convenient location along the new line at an elevation below the Black Chief Reservoir. A small water reserve for the homes on O'Brien Creek would be stored in the 12 in. main. Assuming that a flow rate of 100 gpm through the pumping loop would be adequate to prevent freezing of the lines , (current winter discharge rate is near 100 gpm) a 5 hp pump would be necessary to move the water through a 4 in. PVC line 9000 ft. long, while lifting the water 63 ft. to the O'Brien Creek

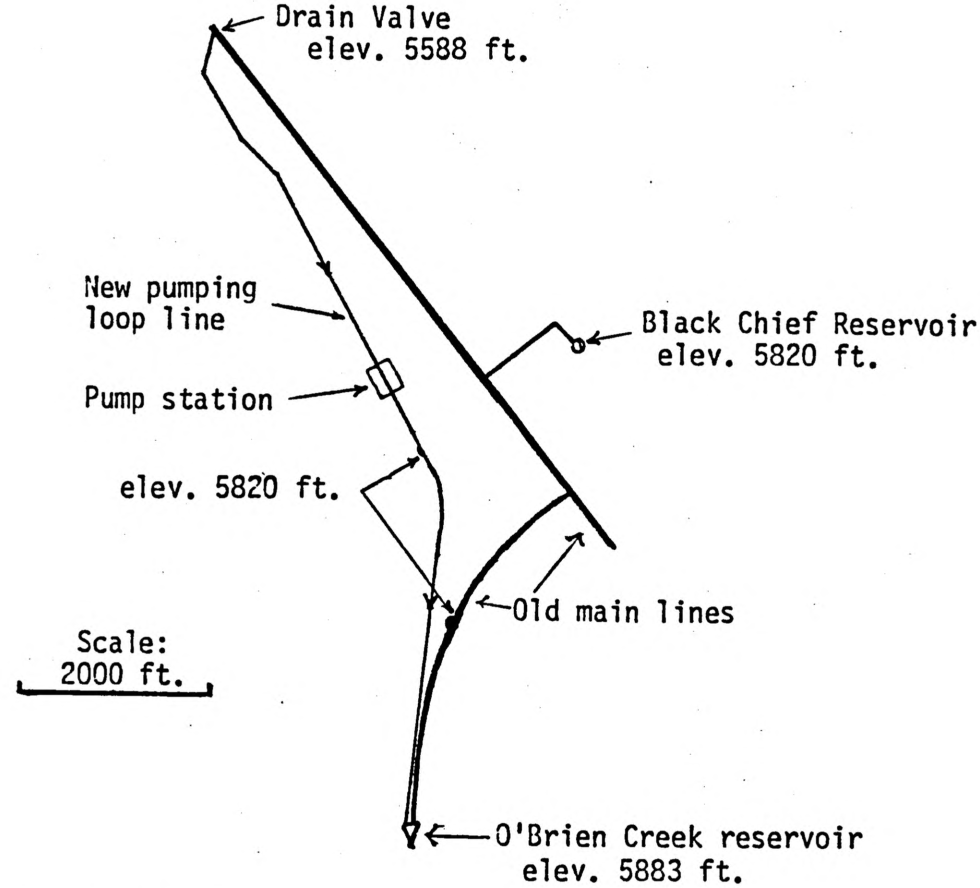

Figure 4. Pumping loop system

Table 1. Pumping system cost

Item	Cost Amount, $
5 hp pump, 2 @ $900 each (one back-up pump)	1,800
4 in. Schedule 40 PVC pipe, 9000 ft	15,100
Pump building, valves, electrical hook-up	10,000
Excavation and covering of water line, 4 ft deep using backhoe and dozer	34,000
total	60,900

Reservoir. Total approximate cost for this system, as detailed in Table 1, is about $61,000.

Pumping costs for the system operating at full rate from December through April and at half rate for the remainder of the year, based on current Montana Power Co. rates, would be about $143 per month in the winter and $44 per month during the other months. Total yearly electrical cost would be approximately $1023. A small maintenance cost would also be incurred.

Discharge Systems

Discharge systems protect the main lines from freezing by allowing water from O'Brien Creek to flow through the system and into Belt Creek, much like current winter operation.

Chlorinated Water Discharge

State standards require a chlorine residual be maintained in the distribution system if a surface water source is used, and the state recommends a free available chlorine (FAC) residual of 0.2-0.5 mg/1 be maintained in systems which adeqately treat surface waters. Therefore the water wasted to Belt Creek will result in a chlorine concentration in Belt Creek. Based on breakpoint chlorination phenomena it can be assumed the combined available chlorine (CAC) concentration in the discharged water will be negligible. A discharge permit for Belt Creek will have to be secured from the state if water is discharged into the Creek. The discharge permit will establish the maximum acceptable residual chlorine level in Belt Creek, which should be near 0.05 mg/l based on waste water discharge permits. The current system could be operated if water from O'Brien Creek was treated to meet State standards, and a FAC residual was maintained in the system, and the maximum chlorine level in Belt Creek was not exceeded.

The resulting chlorine level in Belt Creek is dependent on the flow rate of Belt Creek, the rate of discharge into the Creek, and the residual chlorine concentration of the discharged water. Figure 5 shows the resulting residual chlorine concentration in Belt Creek at varying flow rates of Belt Creek if water with a FAC concentration of 0.3 mg/l enters the stream at 100 gpm. In the above figure it was assumed that the discharge stream contained no CAC, no free chlorine was lost in mixing, and mixing was instantanous.

In order to determine the possible range of flow rates in Belt Creek at the point of mixing a flow duration curve was developed for the site using the method of Cunningham and Peterson. This curve predicts flow rates as a function

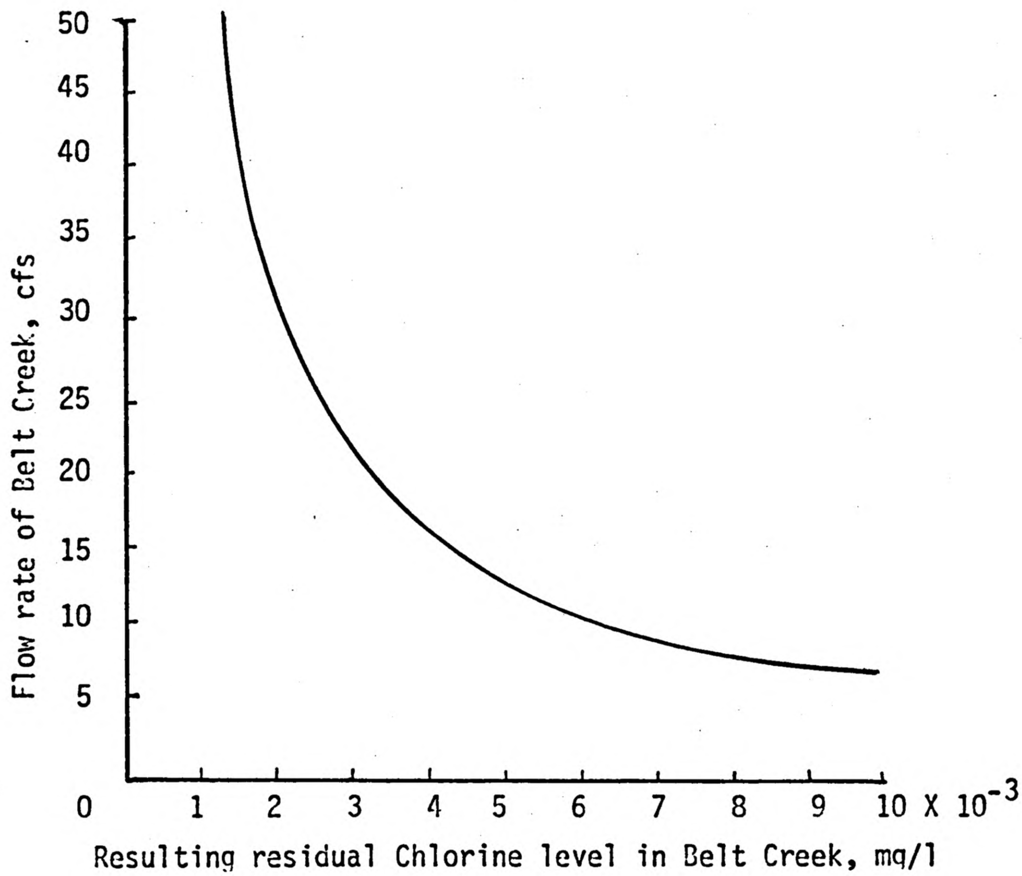

Figure 5. Resulting residual Chlorine Level in Belt Creek for 100gpm of water discharge with FAC=0.3 mg/l. (1 cfs=448.8 gpm)

of percent exceedence. As shown in Figure 6, a flow rate of 18.2 cfs would be exceeded 50% of the time. The 99% exceedence flow rate is about 7.5 cfs.

At a flow rate of 7.5 cfs, the flow rate that is exceeded 99% of the time, a discharge rate of 100 gpm of water with a FAC concentration of 0.3 mg/l would result in a residual chlorine concentration of 0.009 mg/l in Belt Creek. These conditions do not exceed the 0.05 mg/l residual chlorine standard for the receiving stream. The maximum FAC concentration acceptable in the discharge stream at a flow rate of 100 gpm and at the 99% exceedence flow rate would be 1.7 mg/l as shown in Figure 7. All the above data lead to the conclusion that chlorinated water could be discharged to Belt Creek during the winter under the expected range of normal operating conditions. Under worst case conditions the residual chlorine level would be expected to be well under 0.05 mg/l.

Water Demand.

On Saturday, August 16, 1986 at 10:30 AM the flow rate out of Black Chief Reservoir was measured at 195 gpm with the system drain open, similar to normal winter operation.

Based on this measurement, any discharge system should provide an additional 100 gpm of water above the 100 gpm supplied by Black Chief Spring to meet winter demand when discharging water. Following are design estimates for and

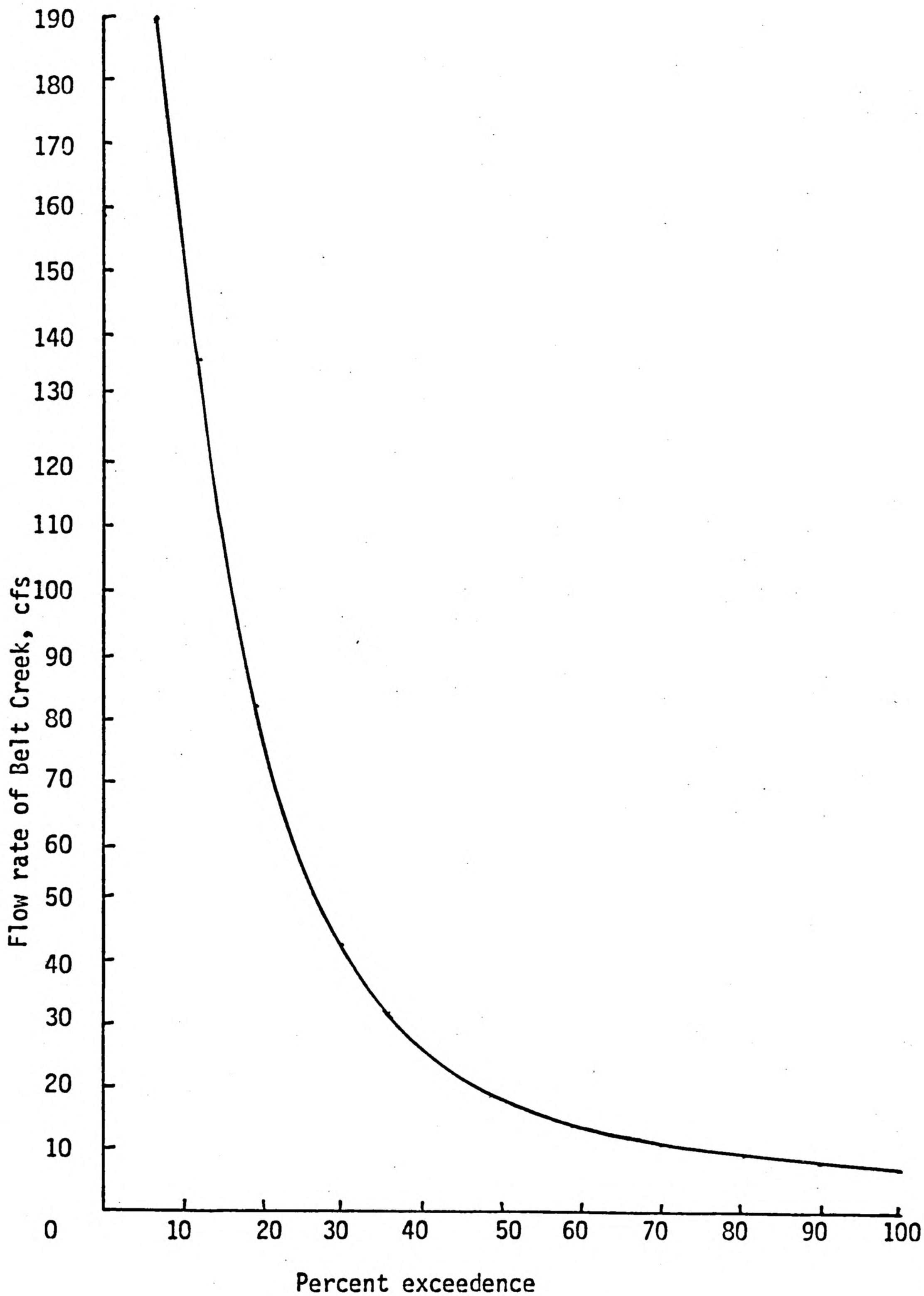

Figure 6. Flow Duration Curve for Belt Creek at Neihart, MT.

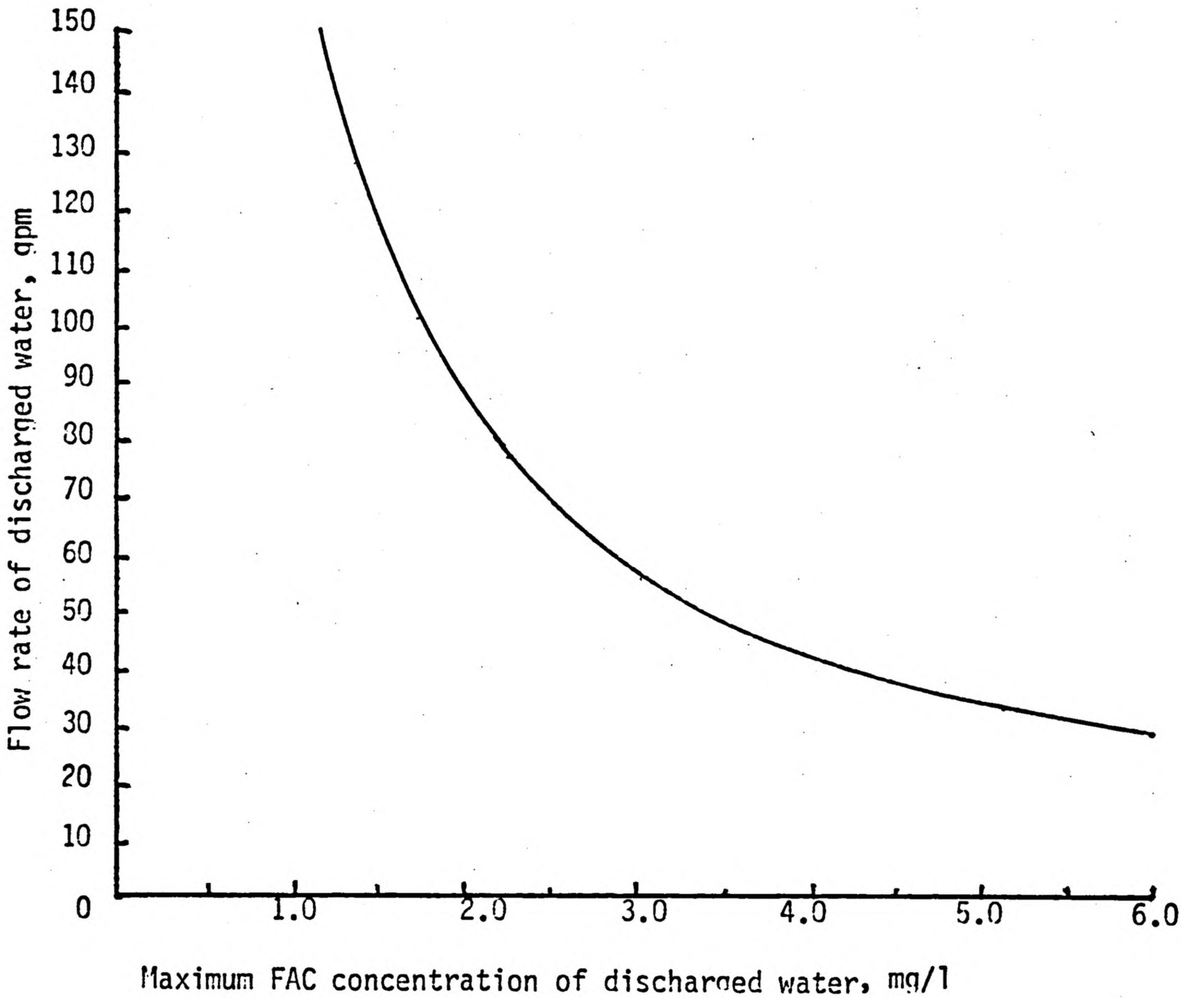

Figure 7. Maximum FAC chlorine concentration of discharged water versus discharge rate resulting in a residual chlorine concentration in Belt Creek less than 0.05 mg/l. Flow rate in Belt Creek = 7.5 cfs

descriptions of treatment systems capable of supplying 100 gpm of treated water from O'Brien Creek to the distribution system. Because a surface water is being used in the system a chlorine residual must be maintained in the system, making chlorination of Black Chief Spring water necessary.

One should note that a discharge system will have a steady winter demand and an additional varying demand related to community water use patterns. The treatment system to be added will meet the year-round demand of the community, and part of the additional winter demand. Water from Black Chief spring will be used in the winter to supply needed make-up water. O'Brien Creek water will be supplied to the entire community year-round, including those homes that can not normally be served by Black Chief reservoir.

Because of the chlorine residual requirement in the system, Black Chief Spring water will have to be chlorinated, making installation of a chlorination facility on the Black Chief supply line necessary.

Winter operation of the discharge system will require that the rate of discharge and water use is equal to or greater than the rate of production of treated water. At discharge and use rates greater than the production rate, make-up water would be drawn from the Black Chief source.

If the combined use rate drops below the production rate, treated water will have to be wasted before entering the system, after filling any storage capacity on the O'Brien Creek line.

Summer operation will require matching the daily water production rate to the daily use rate and by-passing the pressure reduction valve, allowing Black Chief Reservoir to fill with treated O'Brien Creek water. Hourly variations in demand would be met by O'Brien Creek water stored in Black Chief Reservoir. Black Chief water would not be used during the summer. A small reserve of water would have to be maintained above the homes on O'Brien Creek that are at elevations above the Black Chief Reservoir so that these homes would have some water reserve available.

Several modifications to the O'Brien Creek Reservoir have been suggested to incorporate some type of a filter system within the Reservoir itself. It is very unlikely that any such system would meet State approval as a treatment system and there are certain details associated with these systems that may make each system unfeasible. A major concern is related to seasonal variation in water flow. If a filter, possibly a sand bed, was constructed in the bottom of the Reservoir, a large spring run-off may completely destroy the filter. Winter operation and maintenance of a system may be very difficult under a layer of ice. Systems in the Reservoir may quickly silt in or be clogged with detritus. Thus, these systems will not be considered herein.

The Reservoir will function in all of the following systems as a settling basin. This basin will aid in reducing peaks in raw water quality, and most large particles will settle, removing them before any treatment.

Recall that surface water must be treated as if *Giardia* is present. Because of the chlorine residual level in Belt Creek and lack of a detention basin immediately after chlorination, the O'Brien Creek water can not be chlorinated with sufficent contact time to inactivate *Giardia* cysts. Black Chief reservoir can not be used to provide contact time because O'Brien Creek Water would reach some homes before entering the reservoir. Therefore, the O'Brien Creek water must be filtered to remove the cysts and other matter which causes turbidity, then chlorinated.

Raw Water Quality

Water quality analysis and current and projected water demand provide the basis for treatment system selection and design. Representative water samples should be collected and analyzed for turbidity, suspended solids, pH, alkalinity, hardness, sodium, chlorides, iron, manganese, algae, and organic compounds. Sufficent samples should be taken to characterize the range of each of the above parameters.

Because data of this type has not been collected for O'Brien Creek water, the following assumptions have been made to aid in the treatment selection and design process.

1) The turbidity of the water is under 10 NTU for all periods except for during a very short period of spring run-off; normal turbidity is under 3 NTU.

2) Large amounts of algae are not present in the water.

3) Excessive hardness, alkalinity, iron, manganese, sodium, chlorides, and organic compounds are not present.

4) The water has a low amount of color, and taste and odor problems will not be encountered.

The above assumptions are reasonable for the O'Brien Creek water. This water has historically been used to supply the community with no treatment other than chlorination, and the water drains from a protected hard-rock mountain watershed. Water quality can be expected to be typical of other mountain sources.

Packaged Treatment Plants

Turbidity removal from the O'Brien creek water will require physical or chemical processes to treat the water. The higher the turbidity, the more complicated the treatment system will be. Several treatment steps may be necessary to adequately remove the turbidity. Packaged treatment systems can be purchased which incorporate all of the necessary processes within a very compact housing, without the high cost involved in engineering a specific treatment scheme. Typical design life for these systems is 20 years.

These systems are designed to simplify operations and minimize labor. Often automatic controls are incorporated so that constant supervision is not required. Operators only need a small amount of training.

Packaged treatment systems can be divided into three categories based on treatment methods used. Each system is best suited to treat raw water of a particular quality range.

1) Direct filtration
2) Direct filtration with coagulation
3) Complete conventional treatment systems

Based on the above assumed raw water quality conditions direct filtration and direct filtration with coagulation should be considered (USEPA, 1983). Direct filtration methods include slow sand filtration and diatomaceous earth filtration, these methods will be considered later. Direct filtration with coagulation, the most complicated treatment method of the three, will be considered first.

Direct Filtration With Coagulation

This is a two step process, where the first step chemically prepares the water to remove suspended matter, and in the second step the suspended matter is physically removed. The water is chemically prepared in a process called coagulation.

The process of coagulation uses chemicals to aid in the formation of large, easy to remove particles by the aggregation of the small particles present in the water. Larger particles then can be removed by settling and/or filtration. The large particles that are formed are called flocs. The process of forming the particles is called flocculation. Coagulating chemicals initiate flocculation by chemical mechanisms specific to the coagulating chemical. Chemicals used for coagulants include alum and organic polymers. Required coagulant dosage is dependent on the constituents present in the raw water and their concentration.

After coagulation and flocculation, the large particles are removed by sedimentation and/or filtration. Sedimentation may be necessary when the raw water is of high turbidity and hence a large amount of material must be removed. For the O'Brien Creek water the turbidity is sufficently low, hence the sedimentation step can be omitted. Flocculated particles will be removed by filtration.

Filtration removes particles by three principal mechanisms (USEPA, 1983):

1) Surface filtration - large particles settle out or are trapped at the surface of the filter bed.

2) Physical straining - smaller particles cannot pass through the gaps between filter particles and are trapped.

3) Adhesion - the smallest solids that can normally pass through the pores of the filter bed may be attracted by weak forces, which are a direct result of the coagulating chemical used, to the surface of the individual filter particles, where they adhere.

The filter type in common use in packaged treatment plants is referred to as the rapid sand filter. Sometimes a multi-media rapid filter is used. The filter consists of a housing to hold the filter media, a filter bed composed of sand or, in the case of the multi-media filter, a bed of sand covered by a bed of coal, an underdrain system to collect filtered water, and a backwash system for cleaning the filter media. A typical multi-media filter appears in Figure 8. Most new water filtration systems use multi-media technology (USEPA, 1983). Most rapid filters rely on gravity for operation. The weight of the water above the media is used to push water through the filter.

Normal filter operation begins with a clean filter media and a shallow depth of water above the media. As

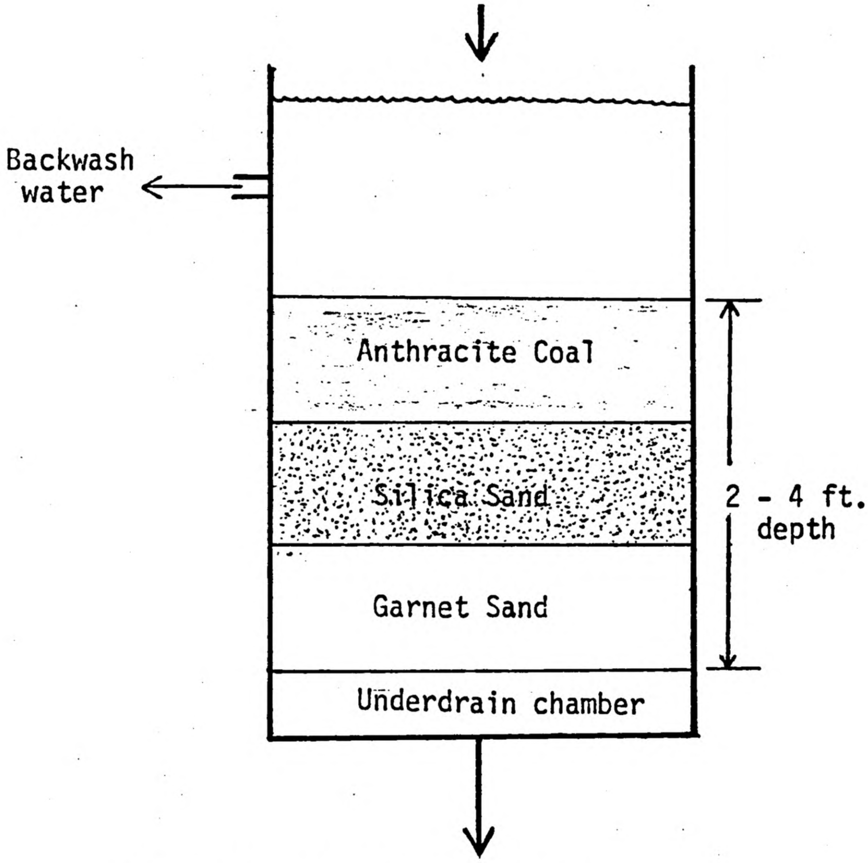

Figure 8. Multi-media Filter

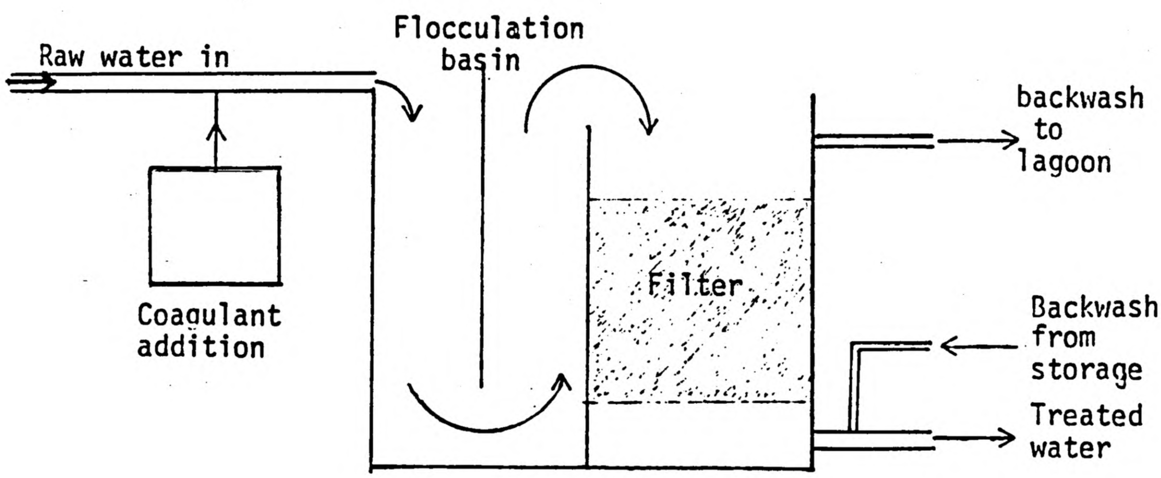

Figure 9. Flow diagram of a Package Plant

filtration progresses particles are trapped in the filter media and on the media surface, effectively clogging the filter. The clogging continues until an adequate flow rate cannot be maintained through the filter with the amount of water depth available. At this point the filter must be taken out of service and cleaned. Filter rates range from 4 to 6 gpm/sq ft. Filter run times before backwashing can range from a few hours to several days depending on raw water turbidity.

Backwashing forces water through the filter in the direction opposite normal flow at a rate sufficient to fluidize the filter bed. The particles that have been trapped in the filter are carried out with the wash water, which then normally proceeds to a settling pond, where the particles settle out. The wash water is recycled. Backwashing may consume up to 10% of the filtered water supply, flowing at rates of 10 to 20 gpm/sq ft. (USEPA, 1983).

After washing, the filter is put back on-line. During the beginning of operation the filter is allowed to ripen. The ripening period is marked by poor water quality from the filter as remaining backwash water is expelled and the surface of the filter develops. Effluent water from the filter during this stage is wasted to the feed reservoir.

A direct filtration with coagulation plant is composed of three main process areas. First, chemical coagulants are added to the water. The water then proceeds into an agitated detention basin where flocs are formed. Lastly, the water passes through the filter, where the flocs are removed. The plant also requires some support facilities. A source of filtered water must be available for backwashing. A nearby reservoir or clearwell fills this need. Additionally, the backwash water and the initial filter effluent during the ripening stage must be wasted to a lagoon before recycle. Solids washed from the filter settle in the lagoon, and clear water from the lagoon returns to the plant influent stream. The total system includes the package treatment plant, a settling lagoon, and a clear water storage reservoir.

Construction and operating and maintenance costs for the entire system are detailed in Tables 2 and 3.

Diatomaceous Earth Filtration

Diatomaceous earth filters have been applied to drinking water treatment as well as for filtering swimming pool water. Advantages of Diatomaceous earth filters include low cost and compact size. Filters are best suited for continuous flow of water of turbidity less than 10 NTU. Because of filter cycle times and ease of operation, labor requirements are small. Diatomaceous earth filters are most commonly available as package treatment plants. These

Table 2. Direct Filtration with Coagulation Treatment Plant Construction Costs.

Item	Cost,$
Package Treatment Plant - 100 gpm	182,000
Steel Backwash/Clearwater Tank - 30,000 gal	38,000
Sludge Lagoon - 5,000 sq ft.	3,900
Total	224,300

Table 3. Direct Filtration with Coagulation Yearly Operating and Maintenance Costs.

Category	Amount	Rate	Cost,$
Electrical Energy	114,700 kw-hr	$.045/kw-hr	5,161
Maintenance material	-	-	262
Labor	2540 hr	$8/hr	20,320
Fuel (for lagoon cleaning)	100 gal	$1/gal	100
		Total	25,803

filters have been proven to be effective at removing Giardia cysts.

The filter uses a precoat filtration process. Essentially the filter consists of the septum, which holds the filter media, a housing for the septum, and a pump to provide energy to pass water through the media and septum. See Figures 10 and 11. A thin layer of Diatomaceous earth is deposited on the septum at the beginning of the filter cycle. This is the precoat process. Filtration rates of 1 to 2 gpm per square foot of filter area are common. A precoat filter removes solids at the media surface by forming a cake of these solids on the raw water side of the filter medium, probably by the simple mechanism of mechanical straining (Weber, 1972).

The filter cycle consists of three steps (Weber, 1972):

1) Precoat application,
2) Filtration of water with body feed,
3) Removal of the filter cake at the end of the run.

Precoat application adds 0.1 to 0.2 lb of diatomite per square foot of filter septum to form a cake of a thickness of about 1/8 in. As filtration progresses, solids are removed on the precoat surface. Body feed of diatomite at about 20 mg/l is added to lengthen the filter run time due to compression of precoat solids. As the run

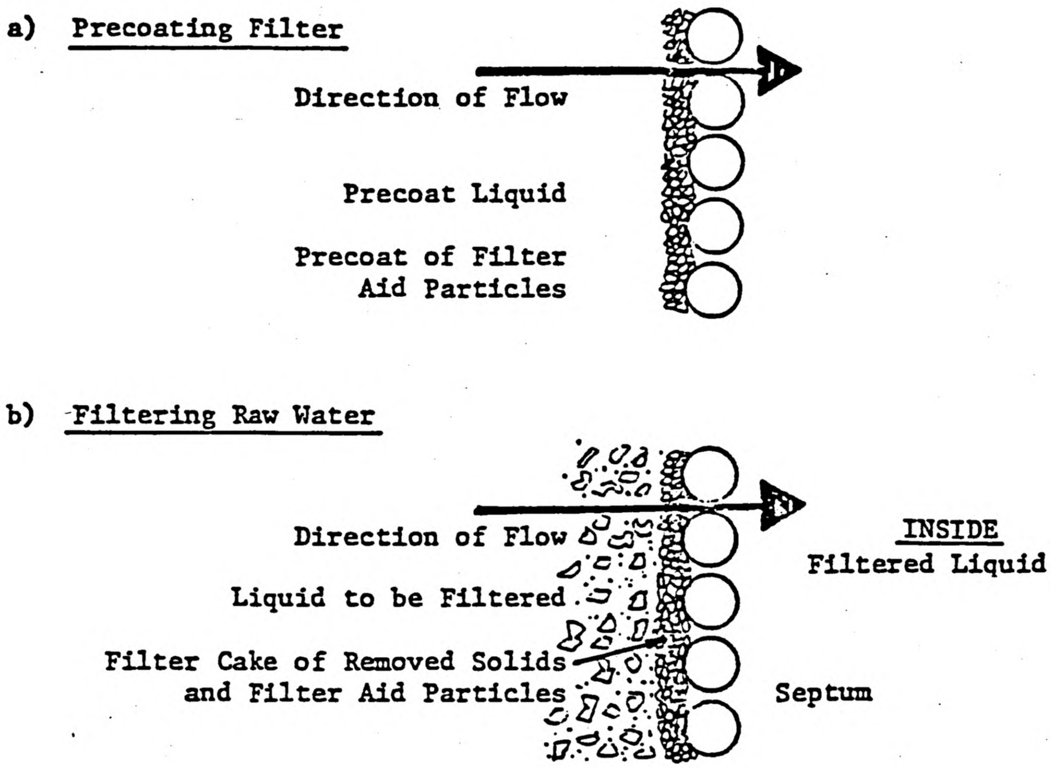

Figure 10. Diatomaceous Earth Filtration (from U.S. EPA, 1983)

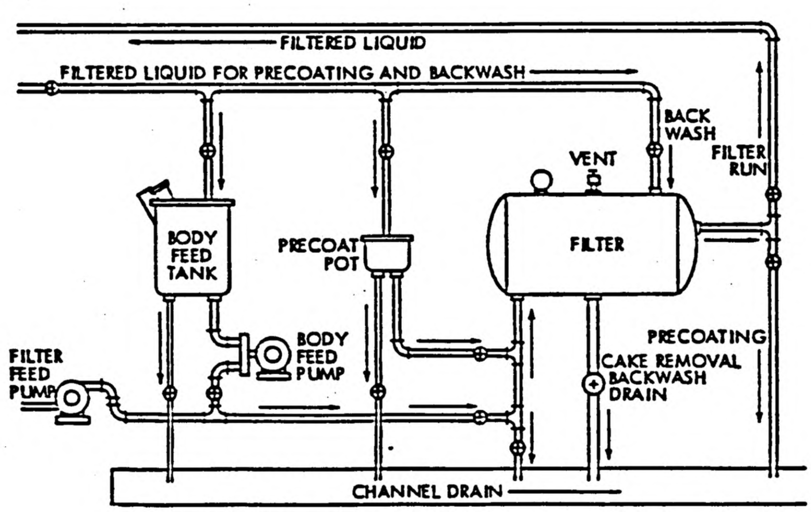

Figure 11. Flow Diagram of a Pressure Precoat Filter
(Courtesy Johns Manville Corp. in Weber, 1972)

progresses the pressure drop across the filter increases until a limit is reached. The filter cake is hydraulically removed and the cycle begins again. Typical cycle time is 24 hours. After fresh precoating the filter is returned to service.

A complete Diatomaceous earth system for Neihart would include a package treatment plant, a small clearwater reservoir for backwashing and reserve for homes on O'Brien Creek, and a sludge lagoon for collection of wasted filter cake. Costs for the system are detailed in Tables 4 and 5. Note that the cost of the Diatomaceous earth is included in the yearly operating and maintenance cost, as this is a major expense in this type of system. Spent Diatomaceous earth must also be disposed of. Estimates based on average dosages indicate a yearly output of 14,200 lbs. This amount may pose a disposal problem. The spent earth must be hauled away and disposed of in an acceptable manner.

Slow Sand Filtration

In slow sand filtration, water is passed through a bed of fine sand. As water moves through the filter, suspended matter in the water is largely removed in the upper one inch of the filter media. Low rates of filtration ranging from 80 to 200 gpd/sq ft. of filter area are common, hence the name slow sand filtration. The treatment process is unsophisticated; chemical pretreatment is not necessary and

Table 4. Diatomaceous Earth Filtration Plant Construction Costs.

Item	Cost,$
Package treatment Plan	88,200
Steel Backwash/Clearwater Tank - 5000 gal	10,500
Sludge Lagoon	3,900
Total	102,600

Table 5. Diatomaceous Earth Filtration Plant Yearly Operating and Maintenance Costs.

Category	Amount	Rate	Cost,$
Electrical Energy	40,000 kw-hr	$.045/kw-hr	1,800
Maintenance Material	-	-	550
Labor	1,000 hr	$8/hr	8,000
Fuel	100 gal	$1/gal	100
Diatomaceous Earth	14,200 lb	$.20/lb	2,840
		Total	13,290

operator attention is minimal.

Overall, the operation and maintenance of a slow sand filter is relatively uncomplicated. An operator need only make daily adjustments of filtration rate and checks of turbidity and head loss. Labor needs are only extensive when filters must be cleaned. Very little equipment is required in the treatment process and no complicated automatic control systems are involved. Operators will require very little training.

Slow sand filters have been shown to be very effective at removing suspended matter, bacteria, and viruses (Cleasby, et.al., 1984; Fox, et.al., 1984; Sleazak, et.al., 1984; Hofkes, 1983; Huisman and Wood, 1974). Results of a pilot study in which turbidity, particle count, and total coliform count were monitored indicate that when raw water quality is high, slow sand filtration outperforms direct filtration operating with alum or cationic polymer as a coagulant (Cleasby, et.al., 1984).

Slow sand filtration has been used extensively in Europe. The filters have not been successful at removing suspended matter from clay-bearing waters of the midwestern U.S., limiting use of slow sand filtration in the U.S. Most operating facilities in the U.S. are located in the north eastern states. For watersheds where clay is not present and turbidity is low, slow sand filtration is a viable option. Most slow sand filters use reservoirs or lakes as a raw water supply (Slezak, et.al., 1984).

Removal of suspended matter is accomplished by a combination of processes including straining, sedimentation, adsorption, and, most importantly, biochemical and microbial actions. The majority of particles are removed in the top layer of the filter. Filtration forms a mat of microbes and deposited matter on the top layer of the filter. Details of this biological filtration process can be found in Slow Sand Filtration (Huisman and Wood, 1974).

At the surface of the filter straining occurs. Particles that are too large to pass through the pores of the biological mat are trapped on the surface of the filter. These particles build up on the surface, plugging the filter and increasing the amount of energy necessary to push water through the filter. When the head loss limit is reached the filter must be cleaned. The biological mat and a thin layer of sand are scraped off the top of the filter and the filter is returned to service after a ripening period. As most of the suspended matter has been trapped in the biological mat and above cleaning the filter removes collected suspended matter and unplugs the filter.

Filter run times can range from 10 days to 4 months depending on raw water quality. In U.S. practice, the average run time is 48 days. Longer runs occur during the winter and fall than in the spring and summer (Slezak et.al., 1984). After cleaning, a period of two or more days of wasted water operation is necessary as the filter becomes effective once again (Hofkes, 1983).

The microbial processes that make slow sand filtration effective must be established on the filter media. During ripening the microbial community necessary for filter operation becomes established in the new top layer of the filter media. Filters with new sand added to them will require a much longer period for microbial establishment, perhaps up to one month. A total sand depth of about 2.5 ft is necessary for the complete biological action.

Re-sanding becomes necessary after successive scrapings have left the bed thickness at the minimum required thickness. About one foot of additional sand, which has been fouled by biodegredation products, is also removed. Then the filter box is refilled to the original level with clean sand. A layer of dirty sand is redistributed over the top of the media to accelerate the ripening processs.

The slow sand filter consists of a tank about ten feet deep. At the bottom of the tank an underdrain system is constructed and covered with graded gravel to support the sand media. New sand media at the start of the filter life has a thickness of about 4 ft. Available head above the media will be near 5 ft.

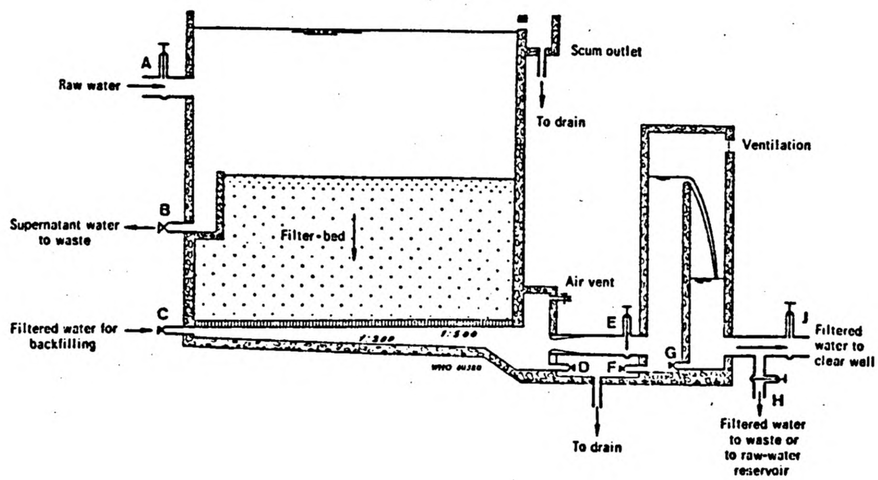

Figure 12. Slow Sand Filter (from Huisman and Wood, 1974)

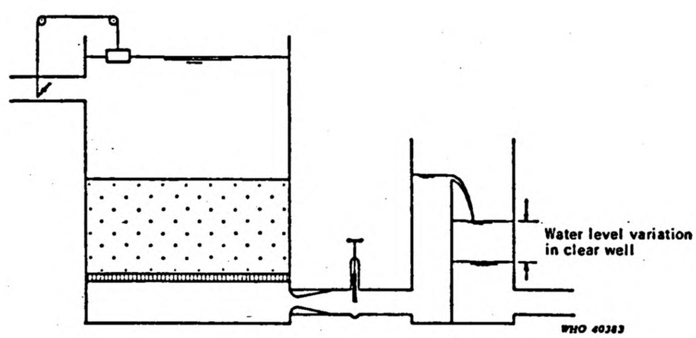

Figure 13. Effluent Filter Rate Control (from Huisman and Wood, 1974)

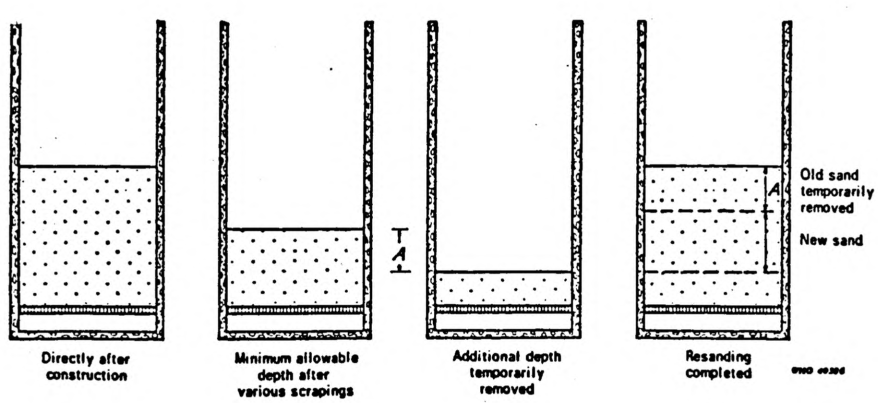

Figure 14. Re-sanding of a Slow Sand Filter (From Huisman and Wood, 1974)

Sand used for the media can be much finer and less uniform than sand required in rapid sand filtration. Sand with an effective size of about 0.2 mm and a uniformity coefficent less than 3 will be satisfactory. Builders grade sand usually satisfies these requirements. Pilot studies with "clean builders sand" and "locally available unsieved sand" produced water of acceptable quality (Fox, et.al., 1984, Slezak, et.al., 1984).

If questions exist about the suitability of the raw water for treatment by slow sand filtration a pilot-plant investigation should be undertaken to verify treatability before a slow sand filter plant is built (Fox, et.al., 1984).

All slow sand filtration systems are custom designed (U.S. EPA, 1983). A system for Neihart with a design capacity of 100 gpm would require a filter surface area of 1400 sq ft. at a filtration rate of 100 gpd/sq ft. The climate would require the filters to be enclosed and heated when necessary. Covering the filters will prevent freezing in the winter and algal growth in the summer. Both conditions may plug the filters. Operation of the filters will also be more predictable in a controlled environment.

Cost data could not be found for slow sand filters, as very few have been built in the U.S. Tables 6 and 7 present rough cost estimates. Construction cost for the filters is based on the construction cost of a concrete reservoir with a volume equal to the volume required for the filters plus a 50% allowance for the cost of piping, valves, and filter media. The cost for the building is the cost for a 2500 sq ft. steel industrial building with R-30 insulation.

Actual design of the treatment system would include four filters each with an area of 500 sq ft. At any time three of the filters would be operating and the remaining filter would be out for maintenance. As one filter became plugged the recently cleaned filter would be brought on-line and the plugged filter taken out of service for cleaning.

A 5000 gal reservoir is included for reserve capacity for homes on O'Brien Creek.

A large portion of the yearly operating and maintenance cost is electrical energy required to heat the building. This cost was calculated with an average use value per square foot of floor space heated to 65 degrees F. If this cost could be lowered through energy conserving construction and operating practices the operating and maintenance cost could be substantially reduced. The indoor temperature need only be maintained just above freezing.

Slow sand filters have useful lives of 50 to 75 years, much longer than most treatment systems.

Table 6. Slow Sand Filter Treatment Plant Construction Costs.

Item	Cost,$
Filters	90,000
Building-Insulated Steel, 2,500 sq ft	25,000
Steel Clearwater Tank, 5000 gal	10,500
Total	125,500

Table 7. Slow Sand Filter Treatment Plant Yearly Operating and Maintenance Costs.

Category	Amount	Rate	Cost,$
Electrical Energy	150,000 kw-hr	$.045/kw-hr	6,750
Maintenance Material	-	-	100
Labor	1,000 hr	$8/hr	8,000
		Total	14,850

Combination Systems

Several water systems have been suggested for Neihart. Inherent to the non-discharge systems is uncertainty if Black Chief Spring would provide an adequate supply of water. Discharge systems will provide sufficient water, but expensive, treated water must be wasted to Belt Creek. It may be feasible to construct the pumping loop to prevent freezing and add treated water from O'Brien Creek to meet water need in the system. The amount of make-up water necessary may be small, requiring a small treatment plant on O'Brien Creek. This type of combination system may be the most economical, depending on water needs.

Chlorination Stations

Recall that if a surface water supply is used, a chlorine residual must be maintained in the system. If Black Chief water is used in combination with O'Brien Creek water both sources must be chlorinated. In order to chlorinate both the Black Chief Spring and O'Brien Creek water two chlorination systems will have to be installed, one each line, as near as possible to the water source. As each source will provide nearly equal amounts of water, identical chlorination systems would be used for each. Details of chlorination and chlorination stations can be found in The Handbook of Chlorination (White, 1986). Because of the small flow rates involved, construction costs are not related to flow rates. Using cost data for sodium hypochlorite feed systems (Hansen, et. al., 1979), the constuction cost estimate for each system is $7,100. Cost for chlorine gas feed systems is about $1000 larger. Operation and maintenance cost would be $3,090 per year, not including the cost of the chlorine.

SUMMARY

The alternatives considered herein are listed in Table 8. Key attributes of each system are listed for review.

Table 8. Summary of Systems Considered

Systems	Water Supply Used	Is Supply Adequate?	Comment
(Non-Discharge)			
Distribution System Replacement	Black Chief	Maybe	Proposal was Rejected by Residents.
Pumping loop	Black Chief	Maybe	Most inexpensive alternative.
(Discharge)			
Direct Filtration with Coagulation	O'Brien-Black Chief	yes	Most labor intensive system.
Diatomaceous Earth Filtration	O'Brien-Black Chief	yes	Lowest cost discharge system. Possible disposal problem exists.
Slow Sand Filtration	O'Brien-Black Chief	yes	Least complicated system

Costs for each system considered are listed in Table 9. As pointed out each system has associated advantages and disadvantages. Selection of a water system should be weighed not only on cost but on factors such as simplicity of operation, reliability, and plant siting.

Table 9. Costs for each water system considered

System	Construction Cost,$	O&M Cost,$
Distribution system replacement	440,000	small
Pumping loop	60,900	1023
Direct Filtration with Coagulation	224,300	25,803
Diatomaceous Earth Filtration	102,600	13,290
Slow Sand Filtration	125,500	14,850

The systems that were addressed herein were considered to be very suitable for the Neihart water system, but an exhaustive consideration of available technology has not been made. There may be other treatment methods or distribution systems that would provide a more suitable or economical solution to the problem.

RECOMMENDATIONS

A water system for Neihart must provide an adequate supply of water. Just exactly how much water is needed is not definitely known. Water flows into and out of the system at several locations. For this paper winter demand has been assumed to be 200 gpm: 100 gpm is used and 100 gpm is wasted. With normal water use, excluding irrigation, a 100 gpm source would be capable of supplying a population of about 2500 people.

Before any solution to the problem is selected, the actual water need should be determined. Daily cumulative flows into the system from both sources and cumulative outflows to Belt Creek should be monitored for at least one full year. This data will help in determining the amount of water that is lost in the system. Differences between summer and winter water use will also be very valuable in water demand analysis.

If the decision is made to treat O'Brien Creek water, a sampling program should be instituted such that the expected range of raw water quality parameters can be characterized. The necessary analysis has been mentioned previously.

Before deciding if water is going to be discharged into Belt Creek the acceptable chlorine residual level will have to be definitely known. If this level is set very low, perhaps below 0.005 mg/1, discharging may become a problem.

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APPENDIX

Abbreviations used:

CAC	Combined Available Chlorine
cfs	cubic feet per second
elev	elevation
FAC	Free Available Chlorine
ft	foot
gal	gallon
gpd	gallons per day
gpm	gallons per minute
hp	horsepower
hr	hour
in	inch
kw-hr	Killowatt-hour
lb	pound
mg/l	milligrams per liter
NTU	Nephelometric Turbidity Units
PVC	Poly vinyl chloride
sq ft	square foot