January 1984

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Recommended Citation

Burns, Susan K.; Adams, V. Dean; and Maloney, Steel B., "Direct Filtration Versus Conventional Water Treatment in the Intermountain Region" (1984). *Reports.* Paper 580.
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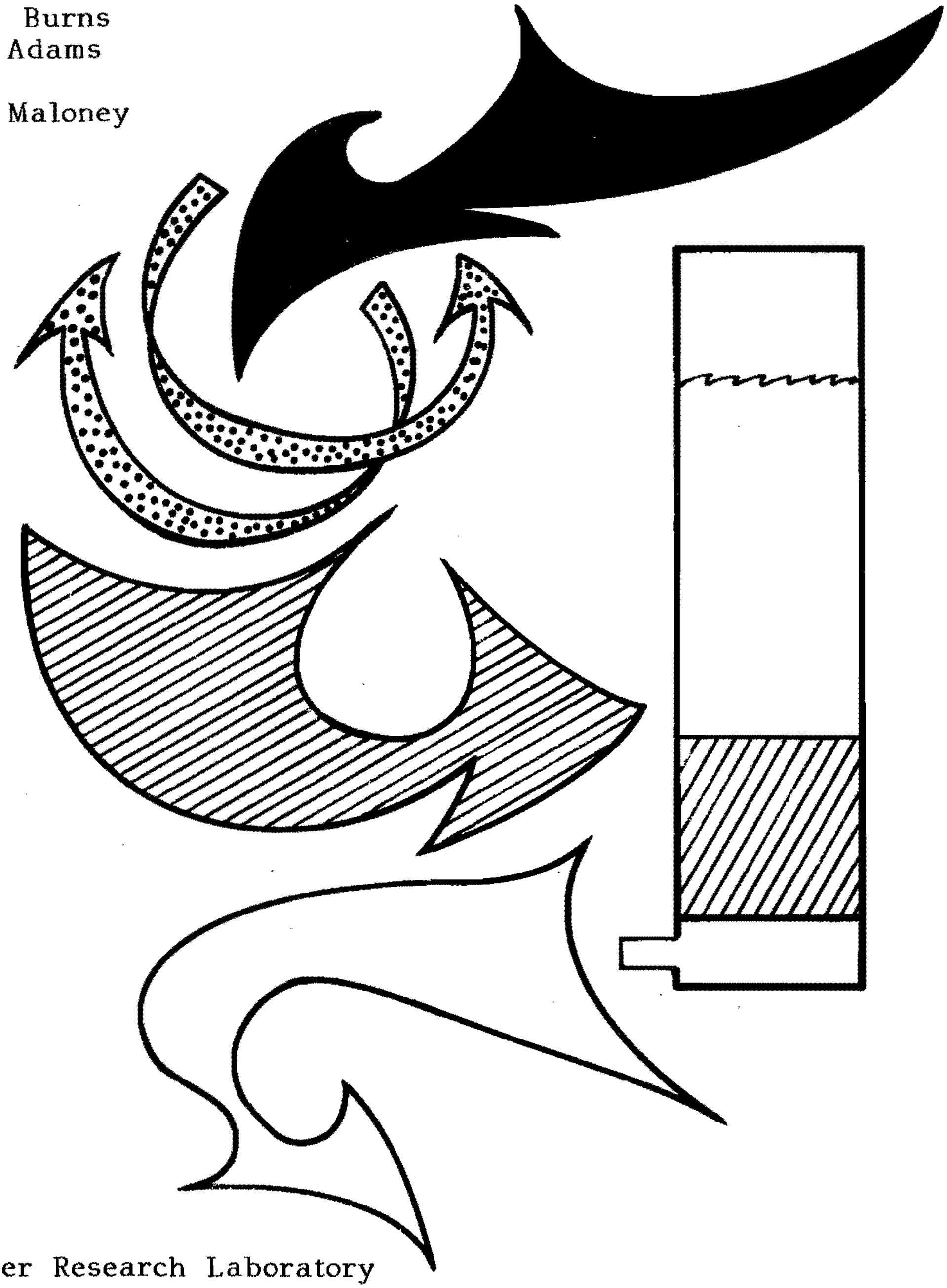

Utah Water Research Laboratory
Utah State University
Logan, UT 84322-8200

September 1984

WATER QUALITY SERIES
UWRL/Q-84/02

DIRECT FILTRATION VERSUS CONVENTIONAL WATER TREATMENT IN THE INTERMOUNTAIN REGION

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ABSTRACT

The direct filtration water treatment scheme does not include sedimentation and in some cases flocculation. Compared to conventional treatment, direct filtration has lowered capital costs, reduced space requirements, decreased sludge quantities, and reduced coagulant dosages.

One objective of this research was the statistical comparison of the direct filtration, Utah Valley Water Purification Plant (Orem, Utah) and the conventional Little Cottonwood Water Treatment Plant (Salt Lake City, Utah). These treatment plants are the two most compatible treatment plants having the highest correlation of source water in the local area. The Little Cottonwood plant receives approximately 65 percent of its source water from Deer Creek Reservoir whereas the Utah Valley plant receives all of its source water from Deer Creek Reservoir.

Data from August 1, 1980, through August 31, 1983, were obtained from the daily water quality and plant operation logs of the two treatment plants. Utilizing the computer, the data were blocked into season means and compared statistically in several fashions. The water quality parameter of most importance in the comparison is the finished water turbidities.

The most beneficial results were obtained from a two-way analysis of variance using an F-ratio as the reference for significance. The F-ratio for the finished water turbidity at the degree of significance, $\alpha = 0.01$, proved not significant. The overall statistical analysis exhibits that the Utah Valley plant produces not only acceptable finished water turbidities well below EPA's maximum contaminant level of 1 TU, but one that is also comparable in quality to that of the conventional processes of the Little Cottonwood Treatment Plant.

Another objective of this research was the operation of two pilot-scale direct filtration systems at the Utah Valley treatment plant. The pilot plant treated the same source water and used the same dual-filter media as the Utah Valley treatment plant. The pilot plant flow processes consisted of a rapid mix basin, a flocculation basin, and the filter column.

Filters were evaluated by the filter performance index (F.P.I.), which is based on the quantity of turbidity removed, the volume of water produced during a filter run, and effluent quality. The highest F.P.I. values were achieved during the filter runs using alum as the primary coagulant and a cationic polymer as a coagulant aid. These filter runs produced a product water with finished water turbidities considerably below the EPA maximum contaminant level of 1 TU. The most successful filter runs were characterized with filter loading rates ranging from 3 to 5 gpm/ft^2, and alum and polymer dosages ranging from 2.1 to 8.1 mg/l and 0.70 to 2.2 mg/l, respectively. These filter runs treated raw water with average turbidities from 13.6 to 22.8 NTU.

ACKNOWLEDGEMENTS

We would like to acknowledge the U.S. Department of the Interior, U.S. Geological Survey, Contract No. G-872, Project No. 374705, which provided funds for this research (JER-204).

The authors express appreciation to all those who contributed to the success of this study. In particular a special thanks to Merlin Smith of the Utah Valley Water Purification Plant, Larry Scanlan of the Utah Department of Health, and Richard Neilson of the Little Cottonwood Metropolitan Water Treatment Plant for their cooperation, operational data, and time spent in answering our many questions.

Gratitude is also expressed to Dr. Donald Sisson and Dr. David Turner for their help and advice in the statistical analysis. A special thanks is also expressed to Shirlee Hubbard for her skill and patience in typing this report.

Sincere thanks are also extended to the Utah Water Research Laboratory, L. Douglas James, Director, for providing equipment and facilities necessary to complete this study and to the secretarial, drafting, and editorial staff for their assistance in preparation and publication of this report.

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INTRODUCTION

Direct filtration offers a low cost but relatively untested component for municipal drinking water treatment plants. Direct sand filters were tried in the early 1900s but proved unsatisfactory because they quickly became clogged by fine sediments and organic matter. In the following years, particulate matter has generally been removed by chemical flocculation followed by sedimentation within a settling basin. However, sedimentation is expensive and becomes increasingly so as greater removal is required and longer detention times are involved.

In the last 20 years, coarse-to-fine dual and mixed-media filters have been developed that can accomplish economical floc removal without excessive head loss, but their effectiveness in removing pathogens and potentially toxic organic compounds requires further evaluation. The goal of such studies is the design of cost effective direct filtration within a total treatment system for potable water to comply with regulatory standards, recognizing that the best design varies with the characteristics of the raw water. This study examines the effectiveness of direct filtration in satisfying the Utah and National Interim Primary Drinking Water Regulations through a literature review and a performance analysis of a Utah plant.

Since June 1977 when the EPA's National Interim Primary Drinking Water Regulations lowered the maximum turbidity contaminant level from 5 to 1 turbidity units, many communities have been faced with the need for treatment to remove particulate matter from potable water supplies that previously only required disinfection. These regulations, coupled with the increasing demand for treated water for growing urban areas, have intensified the search for low-cost water treatment options. Direct filtration is one method receiving increasing scrutiny and adoption as a means of treating public water supplies. Compared to conventional treatment, direct filtration has lower capital costs, reduced space requirements, and smaller sludge quantities. Moreover, direct filtration offers large reductions in coagulant dosages and chemical costs.

RELEVANCE AND OBJECTIVES OF RESEARCH

Active research is underway on direct filtration in several parts of the nation, and the principal findings are reviewed below. However, the only published literature on the applicability of direct filtration to the raw potable water sources of the Intermountain region was the pilot study for the Central Utah Water Conservancy District (CUWCD) (Tate et al., 1977). This study provided background information for construction of the Utah Valley Water Purification Plant in Orem, Utah.

The Utah Valley Plant, constructed in 1979, is the first direct filtration plant to be operated in Utah. The Duchesne direct filtration facility was the second to be constructed in Utah and has been on line for 2 years. The Southeast Regional Water Treatment Plant (Sandy, Utah) was put on line in April 1984. Currently, the construction of a fourth direct filtration plant is underway in Central Utah.

The Utah Department of Health, Division of Environmental Health, is interested in searching out low-cost treatment facilities that are appropriate for the Intermountain area. In the face of the above four direct filtration plants and the prospects of more to come, the Utah Department of Health is particularly interested in performance evaluations of their effectiveness.

The specific objectives of this research were:

1. Evaluate an online direct filtration facility (i.e., Utah Valley Water Purification Plant, Orem, Utah) and determine parameters appropriate for analyzing the "quality of the product" such that an impartial party can evaluate the water.

2. Determine the ability of a direct filtration system (pilot scale) to remove constituents from surface waters, and subsequently reduce turbidity.

LITERATURE AND BACKGROUND REVIEW

The AWWA Water Quality Division Committee on Coagulation-Filtration defines direct filtration as any water treatment system in which the filtration is not proceeded by in-plant sedimentation of flocculated water. This definition includes systems that utilize either flocculation basins or contact basins not equipped with sludge collection equipment and systems which contain neither. Figures 1 and 2 illustrate typical conventional treatment systems and Figures 3 and 4 illustrate typical direct filtration processes.

History

According to Culp (1977), direct filtration dates back to the early 1900s. At that time several attempts were made to follow chemical treatment with the rapid sand filtration without the use of settling basins. These efforts failed because of rapid clogging in the top few inches of the single media filter beds and subsequent rapid head loss. However, the more recent development of coal-sand, dual-and mixed-media filters permit storage of larger quantities of floc within the filter bed without excessive headloss. This innovation has made the treatment of a wide variety of raw waters by direct filtration feasible.

The direct filtration process is currently being utilized at several water treatment facilities in the United States, Canada, and Australia (Monscivitz et al., 1978, Sweeney and Prendiville, 1974, and Walder et al., 1975). As early as 1964, direct filtration has been used in the province of Ontario at the Toronto Water Treatment Plant on Lake Ontario (Tredgett, 1974, and Hutchison and Foley, 1974). The Toronto plant, constructed in 1917, used drifting-sand filters until 1964 when the plant was converted to direct filtration. In 1973, after this plant proved successful, three additional direct filtration plants were put into operation in Ontario, namely, the Owen Sound WTP on Georgian Bay, and the Lake Huron WTP, and the Port Elgin WTP both on Lake Huron (Foley, 1980). Since that time, several former sedimentation plants have been converted to direct filtration and a number of new plants have been constructed, bringing the number of direct filtration plants in Ontario to 14 (Foley, 1980).

A partial listing of the operating full-scale direct filtration plants (Culp, 1977 and Committee Report, 1980) includes:

Municipal, without contact basins:

Oakland, OR (0.5 mgd)
Veneta, OR
Vail, CO (1.4 mgd)
Camas, WA (2.0 mgd)
Baldwin, KA, iron removal
Bellingham, WA (24 mgd)
Bonner Springs, KA
Las Vegas, NV (200 mgd)
  Alfred Merritt Smith Water
    Treatment Facility
Stonewall OK
Willipa Valley, WA
  East Raymond Water
    Treatment Facility
Ft. Collins, CO (24 mgd)
Bearspaw Dam, Calgary (78 mgd)
Bogota, Columbia
    (200,000 m^3/d)
  El Sapo Water Treatment
    Plant

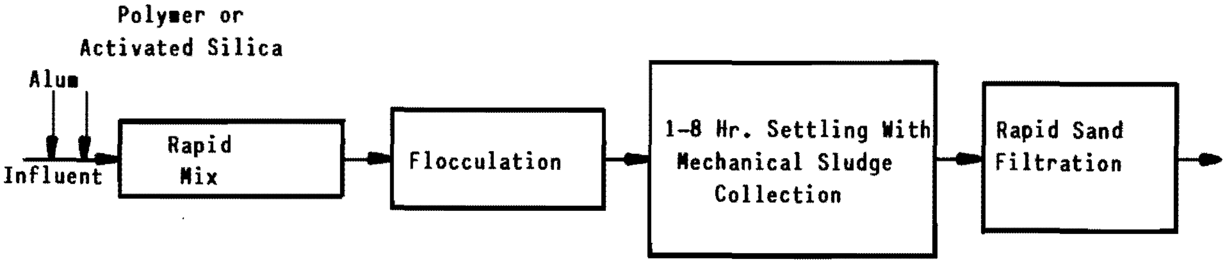


Figure 1. Flow sheet for typical older convention filter plants (Culp, 1977).

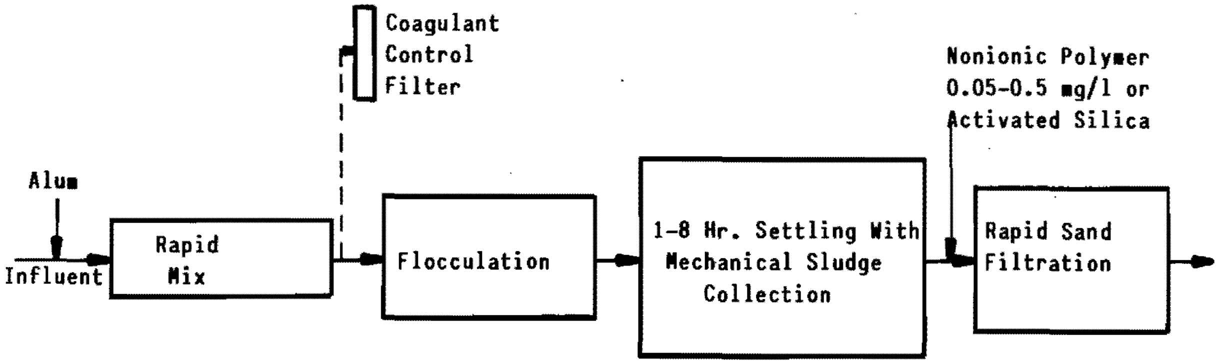


Figure 2. Flow sheet for typical recent design trends for conventional filter plant (Culp, 1977).

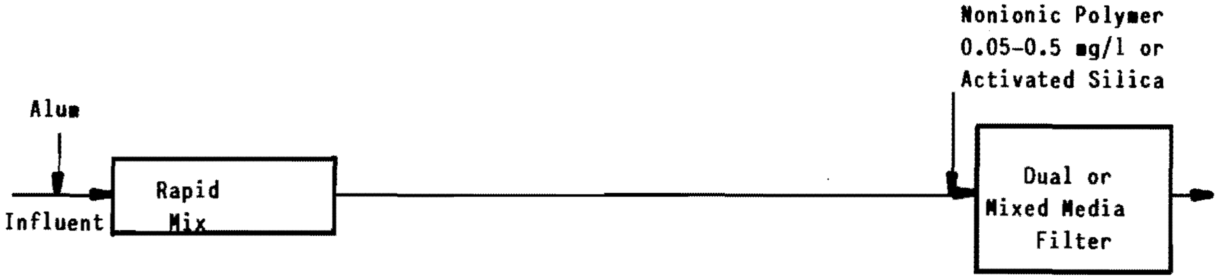


Figure 3. Flow sheet for typical direct filtration using alum and nonionic polymer or activated silica (Culp, 1977).

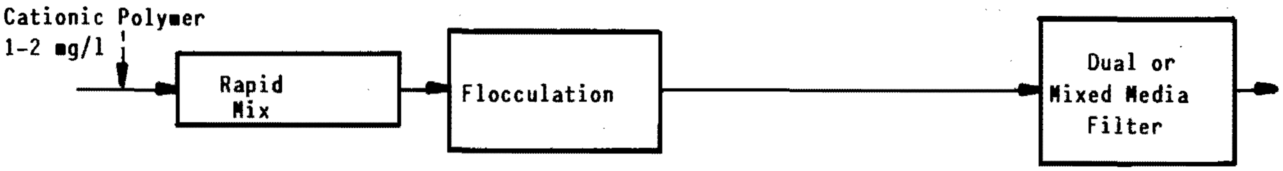


Figure 4. Flow sheet for typical direct filtration using a flocculation basin (Culp, 1977).

Municipal, without contact basins continued:

Dundee, Scotland (24 mgd)
  Clatto Treatment Works
Riverside, ID (1 mgd)

Municipal, with contact basins:

Richland, WA (15 mgd)
Medford, OR (15 mgd)
Lake Oswego, OR (10 mgd)
Peoria, IL (10 mgd)
  Peoria Water Co.
Clackamas, OR (6 mgd)
Whatcom County Public Utility Dist., WA
Denver, CO (120 mgd)
  Havison Water Treatment Plant
San Diego, CA (40 mgd)
  Miramar Filtration Plant
La Mesa, CA (66 mgd)
  Alvarado Filtration Plant
  Pine Valley Water Purification Plant
  Lakewood Treatment Plant
Arvada, CO (9 mgd)
Spiro, OK (1 mgd)
Lower Otay Lake, San Diego County (15 mgd)
Colorado Springs, CO (40 mgd)
Duluth, MN (30 mgd)
Aurora, CO (18 mgd)
Arnprior, Ontario (5 mgd)

Industrial, with contact basins:

Fraser Co. Ltd., New Castle, N.B.

Industrial, without contact basins:

Crown Zellerback, Wauna, OR (50 mgd)
American Can Co., Halsey, OR (18 mgd)
Boise-Cascade Corp., St. Helens, OR (15 mgd)
Publisher's Paper, Newburg, OR
Union Oil Co., Ft. St. John, B.C. (1 mgd)
American Oil Co., Texas City, TX (36 mgd)
Boise-Cascade Corp., Salem, OR
Mobay Chemical Corp., Salem, OR
Skeena Kraft, British Columbia (20 mgd)

Several other pilot plant and full-scale tests have led to the proposal or construction of additional direct filtration plants. One of the largest is the Los Angeles Department of Water and Power (LADWP) direct filtration plant which treats Owens River Aqueduct Water. The Owens River Aqueduct delivers 530 mgd of mountain water to 2.2 million residents in Los Angeles (McBride et al., 1982).

In 1979, the California Safe Drinking Water Act established a stricter turbidity standard of 0.5 nephelometric turbidity unit (NTU) for finished water. The LADWP started a series of studies to determine the most cost effective and efficient method to treat the Owens River Aqueduct Water. The pilot-plant work, conducted by the department and consulting engineers, Brown and Caldwell and Camp, Dresser & McKee, indicated direct filtration to be an effective treatment method for bringing the Owens River Aqueduct water into compliance with the new California standards. The LADWP plant is now under construction and expected to be treating water by August 1985 (McBride et al., 1982).

Pilot plant tests were also used to investigate the feasibility of direct filtration for treating water from Deer Creek Reservoir in central Utah (Tate et al., 1977). The investigators found Deer Creek Reservoir water to have an average turbidity of 2.6 NTU, a minimum turbidity of 0.1 NTU, and a maximum of 60 NTU. This maximum turbidity is within the limits given in Baumann's (1976) statement that direct filtration is a currently accepted technology for producing potable water from a raw water with a turbidity of 50-60 NTU. Furthermore, Letterman and Logsdon's (1976) nationwide survey of operating direct filtration plants meeting the National Drinking Water Standard of 1 NTU indicated that over 50 percent of them had average raw water turbidities exceeding Deer Creek Reservoir's 2.6 NTU. Approximately 40 percent had maximum raw water turbidities in excess of Deer Creek Reservoir's 60 NTU. This experience of others, coupled with the pilot plant tests, indicated that direct filtration would produce an acceptable water and led to the construction of the 42 mgd Utah Valley Water Purification Plant in Orem, Utah, in 1979. Since that time the 4.5 mgd Duchesne direct filtration plant and the 20 mgd Southeast Regional Water Treatment Plant, were put on line in May 1982 and April 1984, respectively. Construction is also underway for a fourth direct filtration plant in central Utah.

Several other case studies on direct filtration were found in the literature. These include McCormick and Kings' (1982) evaluation of direct filtration for treating five different source waters in Virginia; Sequeria et al. (1983) investigated expanding the 70 mgd American River Water Treatment Plant in Sacramento to a new capacity of 105 mgd or more by incorporating direct filtration into their conventional treatment plant; Bowen (1981) studied the feasibility of operating the Traverse City Water Treatment Plant in a direct filtration mode to treat the stable low-turbidity water from Lake Michigan; Westerhoff et al. (1980) conducted a full-scale comparison of direct filtration with conventional treatment for raw water from Lake Erie; Peterson et al. (1980) conducted pilot and full-scale plant studies investigating the effectiveness of treating Lake Superior water for Duluth, Minnesota, for removal of asbestiform fibers by direct filtration. Wagner and Hudson (1982) cite additional examples of direct filtration studies conducted in the United States, Brazil, Guam, Jordan, and West Africa. Case studies are also reported by the Direct Filtration Subcommittee of the AWWA Filtration Committee (1980). Although all of the aforementioned studies were conducted on raw water sources with different characteristics (turbidity, temperature, pH, etc.), each study found direct filtration to be a feasible and effective mode of water treatment.

Direct Filtration--
Process and Operation

Direct filtration differs from conventional treatment systems in that it does not provide sedimentation after chemical addition, coagulation, and flocculation. Solids, both natural and added, must be stored in the filter, making proper coagulation of the suspended particles critical for efficient operation of a direct filtration system.

Raw water characteristics

In evaluating the treatability of a source water by direct filtration several factors should be considered, such as the quantity and character of the particulate matter in the raw water, bacterial quality, taste and odor, color, and the possible formation of trihalomethanes (THMs). From the Committee Report (1980), natural waters with low turbidities and color prove to be most suitable for direct filtration. In the Committee's survey the upper limits of these constituents varied with location as did other water quality factors. In the survey it was also found that there was no set trend toward plant operation, with some plants employing operation techniques designed to overcome specific precluding raw water conditions. In general, the Committee (1980) reports that waters with less than 40 units of color, turbidity consistently less than five units, iron and manganese concentrations of less than 0.3 mg/l and 0.05 mg/l, respectively, and algae counts of up to 2000 ASU/ml, appear to be very good candidates for direct filtration.

Culp (1977, p. 375, 376) states "the possibilities of applying direct filtration to municipal plants are good if 1) the raw water turbidity and color are each less than 25 units; 2) the color is low and the maximum turbidity does not exceed 200 TU; or 3) the turbidity is low and the maximum color does not exceed 100 units." Culp further states that diatom levels in excess of 200 ASU/ml may require coarser top media but are treatable by direct filtration. Reports of successfully handling coliform MPN's of 90 per 100 ml by direct filtration have been received by AWWA with potential for higher coliform removal (Culp, 1977). Treweek (1979) and Tate et al. (1977) have shown direct filtration to be suitable in treating Deer Creek Reservoir (Utah) water with raw water turbidities from 0.1 to 60 TU, successfully achieving the 1-TU limit required by the Safe Drinking Water Act. McCormick and King (1982, p. 241) define raw water characteristics for acceptable treatment by direct filtration as follows: "turbidity, 0-10 NTU; color, 0-15 APHA units; algae (clump count), 0-1000 units/ml." They further concluded that higher values for an individual water parameter could be tolerated when the other raw water parameters were lower.

Often a single parameter such as turbidity is the sole criterion of determining raw water quality for the applicability of direct filtration treatment. Direct filtration methods, while effective for turbidity removal, may be inadequate for plankton and taste and odor removal. It should be the objective of a treatment plant to consider all treatment parameters on an individual basis and under various circumstances such that the design of the plant is tailored to the characteristics of the raw water treated. In order to achieve this, pilot plant studies are necessary in designing any direct filtration plant.

Hutchison and Foley (1974) have demonstrated that data obtained with pilot plant operations correlate well with data obtained from full-scale plant operations if similar media compositions are used. Pilot plant studies will also indicate an optimum type and dosage of coagulant aids required for the raw water to be treated.

Colloidal destabilization

Coagulation captures colloidal particles in the raw water as chemical reactions form a floc (ASCE, AWWA and CSSE, 1969). Two broad classes of materials are removed by coagulation-turbidity and color. The floc forms within seconds of the application of the coagulating reagent to the water. At the point and time of chemical addition, intense mixing is applied to ensure uniform chemical distribution and the rapid exposure of all the fine particles in the water to the coagulating agent before the coagulation reaction is completed. This is achieved in the rapid mix unit, the first process in the direct filtration system.

Colloidal destabilization occurs in the rapid mix unit. In this process, the repulsive forces between colloidal particles are reduced, bringing the colloids together. Colloidal material, because of the small particle size (1-200 nm), has a large ratio of surface area to volume. Because of this immense surface area, colloidal activity is controlled by surface chemical phenomena.

Most colloidal particles in water are negatively charged. A fixed covering of positive ions is attracted to the negatively charged particles by electrostatic attraction during flocculation. This is referred to as the Stern Layer and is surrounded by a movable, diffuse layer of counterions. The diffuse zone extends into the surrounding bulk of electroneutral solution. Figure 5 illustrates this theory.

The surface charge on colloidal particles is the major contributor to their long-term stability; particles which would normally settle or coalesce are naturally repelled. In destabilizing these colloids, there are four distinct mechanisms: 1) compression of

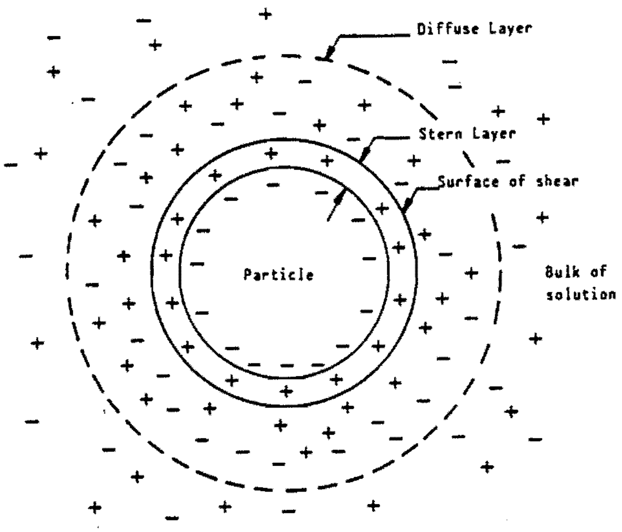


Figure 5. Guoy-Stern Colloidal Model (Clark et al., 1977).

the diffuse layer; 2) adsorption to produce charge neutralization; 3) enmeshment in a precipitate; and 4) adsorption to permit interparticle bridging (Weber, 1972).

In diffuse layer compression, electrolytes are introduced and the repulsive potential energy of the colloidal particle is affected directly by the ionic strength of the surrounding bulk solution. As the ionic strength of the bulk solution increases, the repulsive energy decreases and the volume of the diffuse layer necessary to maintain electroneutrality is decreased, reducing the thickness of the diffuse layer. The compression of the diffuse layer is sufficient enough to permit particles to come in contact with one another and van der Waals' forces of attraction become dominant allowing aggregation to occur. Aggregation of particles in this manner results from contacts by thermal motion, often termed Brownian motion. The transport process of interparticle contacts produced by Brownian motion is termed perikinetic flocculation (Weber, 1972). Electrolytes found to be most effective are multivalent ions of opposite charge to that of the colloidal particles.

For a simplified understanding of charge neutralization by adsorption, it is instructive to consider the energy involved in a simple electrostatic coulombic interaction between a colloidal particle and a coagulant ion. For a simple monovalent ion such as Na^+ and a particle with a potential difference across the diffuse layer of 100 millivolts, the electrostatic energy of the interaction amounts to 2.3 kcal/mole. The electrostatic energy for a hydrogen bond interaction is on the order of 5 kcal/mole and the energy forming a chemical covalent bond is in the range of 50-100 kcal/mole (Weber, 1972). From these numbers it can be seen that many colloid-coagulant interactions can overshadow the coulombic force in colloid destabilization. At an appropriate coagulant dosage, sufficient adsorption will occur neutralizing the charge on the particles, leaving them destabilized.

LaMer and Healy (1963) developed an interparticle bridging theory that provides a qualitative model of the ability of polymers of high molecular weight to destabilize colloidal dispersions. In order for destabilization to occur, the polymer molecule must contain chemical groups that can interact with sites on the colloidal particle. When a colloidal particle and polymer molecule come into contact, some of the chemical groups of the polymer are adsorbed by the particle surface. The remainder of the polymer segment is left extending into the solution, and will attach to a second colloidal particle with vacant attachment sites, forming a polymer-particle complex with the polymer as a bridge (Reactions 1 and 2 in Figure 6). If a second colloidal particle is unavailable, the extended polymer chain will eventually adsorb on other sites on the original particle, and the polymer will no longer be available to serve as

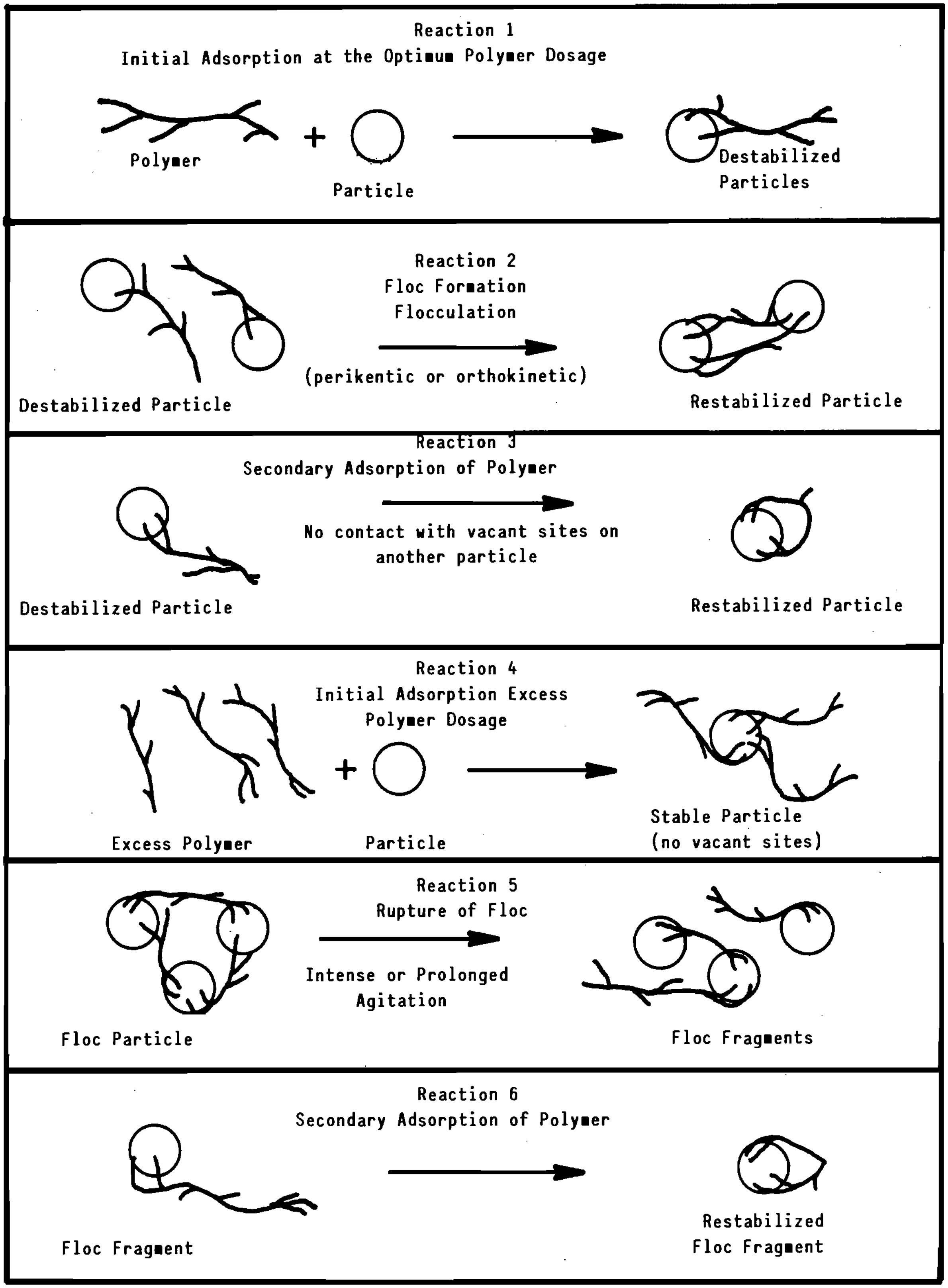


Figure 6. Schematic representation of the bridging model for the destabilization of colloids by polymers (Weber, 1972).

a bridge (Reaction 3 in Figure 6). The energy barrier between colloidal particles is not eliminated by the bridging mechanism, but is superseded by the chemical adsorption energy which can be as large as 100 kcal/mole compared to 2.3 kcal/mole for a simple electrostatic coulombic interaction (Weber, 1972, and Tanner, 1974).

The degree to which particle destabilization and aggregation occur is a function of coagulant dose. High polymer dosage can saturate the colloidal surface, leaving no available reactive sites on the colloid, thus producing a restabilized colloid (Reaction 4 in Figure 6). Low polymer dose results in partial destabilization of the colloidal dispersion, leaving reactive sites available on the colloids but no polymer chains available for bridging. Finally, it has been shown by LaMer and Healy (1963) that a system which has been destabilized and aggregated can be restabilized by prolonged agitation. By extending agitation the polymer-surface bonds can be broken allowing extended polymer segments to be folded back onto the surface of the particles (Reactions 5 and 6 in Figure 6).

As Weber (1972) explains, when a metal salt such as alum ($Al_2(SO_4)_3$), ferric chloride ($FeCl_3$), a metal oxide, or hydroxide in the case of lime, is used as a coagulant in high enough concentrations to cause rapid precipitation of a metal hydroxide or metal carbonate, colloidal particles can be enmeshed in the forming precipitates. The colloidal particles present in the water tend to serve as nuclei for formation of the precipitate, so that the rate of precipitation increases with increasing concentration of colloidal particles to be removed. Thus, the greater the amount of colloidal material to be removed, the lower quantity of metal coagulant needed.

Coagulants

Colloidal destabilization by chemical treatment is an important step to the overall success of direct filtration (Culp, 1977; Hutchison and Foley, 1974; Tredgett, 1974; Habibian and O'Melia, 1975; and Kawamura, 1976). Two experiments with the direct filtration pilot plant conducted by the Central Utah Water Conservancy District (Tate et. al., 1977), one with a coagulant and the other without, were evaluated by Trussell and others (1980). The results showed that although significant reductions in both particulates and turbidity were achieved without chemical addition, the results with chemical addition were significantly better. For particulates, filter performance with a coagulant aid is improved by a factor of nearly 20 (Trussell et al., 1980). Table 1 presents these results. Trussell et al. (1980, p. 709) concluded "the addition of coagulant chemicals is an inherent part of any water filtration process."

The chemicals generally used as primary coagulants for direct filtration include aluminum salts, iron salts, and cationic polymers. Anionic polymers are often used as filter aids to reduce the requirement for primary coagulants. Kawamura (1976) reported that aluminum salts are one of the most effective, economical, and foolproof coagulants in use.

Coagulation by aluminum salts is affected by alkalinity, colloidal concentration, pH, temperature, nature of solids, mixing, and coagulant concentration (Weber, 1972, and McCormick and King, 1982). A problem associated with using aluminum salts as a coagulant has been early breakthrough of turbidity with increasing coagulant dosages. Hutchison (1976) in his studies of Ontario's direct filtration plant on Lake Huron, where alum is the primary coagulant, found that alum dosages less than 3.8 mg/l led to an effluent turbidity in excess of the 0.3 NTU objective. At higher alum doses of 20

Table 1. Filter performance with and without chemical addition at the Central Utah Water Conservancy District Pilot Plant (Trussell et al., 1980).

Run Number	Chemicals - mg/l			Turbidity - TU		Particulates-particles/ml	
	Alum	Polymer*	Chlorine	Raw Water	Filtered Water	Raw Water	Filtered Water
4	0	0	0	0.55	0.24	2000	220
5	3	1.25	1.5	0.57	0.11	1600	14

*Catfloc T. Calgon Corp., Pittsburgh, Pa.

mg/l, polymers were found necessary as coagulant aids to prevent turbidity breakthrough. This combination of high alum dosage and polymer led to short filter runs of less than 10 hrs at loading rates of approximately 5 gpm/sq. ft. (Hutchison, 1976). A concern with using aluminum salts as coagulants is residual alum which may floc after the filtration process and settle out on pipe walls reducing the pipe flow capacity or increase the aluminum concentration in the finished water.

Kawamura (1976) reported that the advantages of using polymers as the primary coagulant include reduced coagulant dosages, reduced sludge volumes with improved dewatering, lowered chemical residuals in the finished water, and fewer problems with alkalinity and pH adjustments. Generally, cationic polymers are used as primary coagulants and coagulant aids, and nonionic and anionic polymers are used as coagulant aids and filter aids. Cationic polymers allow deeper penetration of floc into the filter bed than the nonionic and anionic polymers. Culp (1977) reported that when a cationic polymer is used as the primary coagulant a typical dosage range is 0.1 - 5 mg/l, and for nonionic and anionic polymers (as filter aids) the dosage may be 0.05 to 0.5 mg/l. These dosages are dependent on raw water quality. The Committee Report on the Status of Direct Filtration (1980) states "cationic polymers cannot reduce color to the same degree as metal salts; on the other hand, where turbidity removal is the primary objective, cationic polymers have proved effective and cost effective."

In addition to the previously cited studies of coagulants and coagulant aids in direct filtration, Yeh and Ghosh (1981) conducted a study on selecting appropriate polymers for use as primary coagulants. They found that cationic polymers with low to medium (10,000 to 100,000) molecular weights and high charge densities performed the best. For these polymers it was also found that rapid mixing at velocity gradients of 300-600 sec^{-1} for 3 to 8 minutes was necessary prior to filtration. Yeh and Ghosh (1981) suggest that jar tests with high intensity mixing followed immediately by particle size distribution analysis should be the method of choice for selecting polymers for direct filtration, and that for optimum filtration there exists an optimum floc size dependent on filter and particulate characteristics.

Flocculation

The need for flocculation basins in direct filtration has been an area of controversy among several investigators. Adin and Rebhun (1974) conducted a study on contact flocculation-filtration, where a suitable flocculant was injected into the system just prior to the porous filter bed. They found that high-rate direct filtration allows particulate removal from dilute suspensions without the need of separate flocculation and settling units. In Culp's (1977) investigation of direct filtration, flocculation basins as well as the sedimentation process could both be eliminated without an adverse effect on the filtration process or the finished water quality. Yeh and Ghosh (1981, p. 217) report that, "for most direct filtration operations, slow flocculation following rapid mixing may not be needed, especially if the suspended solids concentration is 30 mg/l or higher."

Treweek (1979), in his phase 2 study of the Utah Valley water purification pilot plant investigation, indicated that the flocculation basin was necessary to achieve the desired level of treatment. In Springfield, Massachusetts, pilot plant studies, Willis (1972) found that a rapid mix and flocculation time of 25 minutes would be required for pretreatment in the direct filtration process. Monscivitz et al. (1978) reported that after the construction of the Las Vegas direct filtration plant, which excluded flocculation, operation difficulties were encountered that led to the addition of flocculation to the treatment process.

Trussell et al. (1980) summarized four different studies evaluating the influence of flocculation on filter performance (Table 2). In general the authors did not feel these results presented any compelling evidence for the necessity of flocculation; however, the need to study flocculation in pretreatment for direct filtration is warranted from the varying results in turbidity and particulate patterns.

The overall goal of flocculation is to produce a floc tailored to the process needs. For direct filtration at high rates a dense, small, pinpoint floc is preferred; opposed to the large, bulky floc desired in conventional treatment systems. This small floc is strong enough to resist the prevailing shear forces, occupies less space in the filter, and fortifies longer filter runs with less breakthrough tendency (Tredgett, 1974).

Previous research has provided a wide range of applicable flocculation times. Sweeney and Prendiville (1974) found that flocculation times should be varied from 10 minutes during hot weather to 30 minutes during colder periods. This was supported by Hutchison and Foley (1974) in their findings that water temperatures below 3.3°C led to slowly forming flocs requiring detention times longer than 10 minutes to prevent after floc formation. They also indicated that flocculation times during warmer weather should be greater than 3.5 minutes to prevent after floc formation, but less than 10 minutes to prevent turbidity breakthrough and rapid head loss accumulation. Hutchison (1976) found in later experiments that the pilot plant filters were more apt to reach turbidity breakthrough at flocculation times greater than 4.5 minutes. This was attributed to the weakening and shearing of the floc caused by continued interparticle collisions and aggregate collisions with the stirring mechanism. Tate et al. (1977) in their pilot plant studies reported that increasing the flocculation time from 13 to 26 minutes did not result in improved water quality, but rather increased the chance of earlier turbidity breakthrough. After the modification of the Las Vegas direct filtration plant to include flocculation, it was found that the Lake Mead water required 15 to 20 minutes of flocculation for optimum reduction of alum, turbidity, and plankton carryover (Monscivitz et al., 1978).

The Committee Report (1980, p. 407) on direct filtration states "there is no unique process that can be said to

Table 2. Influence of flocculation on filter performance (Trussell et al., 1980).

					Media												
			Flocculation		Sand			Coal				Turbidity		Particulates		UFRV	
Location	Alum mg/L	Polymer mg/L	G s^{-1}	Time min.	de mm	Depth mm	Uniformity Coefficient	de mm	Depth mm	Uniformity Coefficient	Number of runs	Raw Water TU	Filtered Water TU	Raw Water Particles mL	Filtered Water Particles mL	m/run	gal/ sq ft/ run
Owens River,	2	2	70	20	0.51	254	1.20	1.1	508	1.24	14	5.0	0.15	8800[a]	21	330	8100
CA (1976)	2	2	0	0	0.51	254	1.20	1.1	508	1.24	8	5.0	0.20	8800[a]	15	281	6900
Lake Casitas	4	1	70	20	0.51	381	1.20	1.1	838	1.24	1	1.6	0.20	2552[a]	57	1590	39000
(1976)	4	1	0	0	0.51	381	1.20	1.1	838	1.24	1	1.6	0.21	2552[a]	68	791	19400
Columbia River,	15	1	75	20	0.54	419	1.24	1.2	838	1.24	3	12	0.12	63000[b]	65	620	15200
WA (1972)	15	1	0	20	0.54	419	1.24	1.2	838	1.24	3	12	0.08	59000[b]	65	611	15000
Wyong, Australia	12	1[c]	75	20	0.50	381	1.30	1.2	762	1.30	1	1.4	0.22	5200[b]	400	155	3800[d]
(1978)	12	1[c]	0	20	0.50	381	1.30	1.2	762	1.30	1	1.4	0.33	6000[b]	402	212	5200

[a] No chemicals added.

[b] Treated water applied to filter. Tested immediately upstream of filter, particles greater than 2.5 microns.

[c] Nalcolyte 801, remainder are Catfloc T.

[d] Terminated by turbidity breakthrough, remainder by limiting headloss.

define direct filtration mixing requirements....no trend in times or energy inputs is evident, although the plants with the fewest problems have control of both the coagulation and the flocculation processes."

Filter mechanisms

The filtration of suspended and colloidal particles from water involves at least two distinct steps: 1) the transport of the suspended particles to the immediate vicinity of the filter grains; and 2) the attachment of these particles to the filter grains or other particles that have been previously deposited in the bed (Habibian and O'Melia, 1975). The transport step depends on physicohydraulic factors including flowrate, filtration media size and shape, filter configuration, bed porosity, and the shape, size and density of the suspended particles. The particles may be transported to the medium by diffusion, interception, gravity settling, or hydrodynamic forces. Adin and Rebhun (1974, p. 109) stated that "the most important conclusion that can be drawn today concerning the transport step is, perhaps, its relative insignificance in filter design." Transport mechanisms appear to be more than sufficient in accomplishing their task even for the most difficult to transport particles. Adin and Rebhun (1974) also stated that by viewing attachment as the major step in the filtration process efforts for filtration might be easier and more worthwhile.

Attachment depends on physicochemical mechanisms. These mechanisms may involve electrostatic interactions, chemical bridging, or specific adsorption, all of which are influenced by pH, ionic composition of the water, age of the floc, nature and dosage of the coagulants, and the composition and surface condition of the medium. The mechanisms of attachment may be considered analogous to those of the previously mentioned destabilization of colloidal particles.

Media specifications

Proper filter media specifications are at the heart of filter design and performance. Selection of a filter medium is dictated by the desired degree of purification, durability of the filter media, length of filter run, and ease of filter wash to remove suspended matter from the media. An ideal filter media should be of such size and specific gravity to provide a satisfactory effluent, retain a maximum quantity of solids, and be easily cleaned with a minimum of wash water (Kawamura, 1975).

The longest filter runs and optimum water production result when in-depth filtration is achieved throughout the filter media. Penetration and removal of the floc throughout the filter bed avoid turbidity breakthrough from unremoved small aggregates, and excessive headloss from entrapment and clogging of large aggregates in the upper layers of the filter media. Several investigations have been conducted to determine the best media configurations for direct filtration with emphasis placed on mixed media and dual media filter beds (McCormick and King, 1982; Hutchison, 1976; Hutchison and Foley, 1974; Monscivitz et al., 1978; Culp, 1977; Tate et al., 1977; Sequeria et al., 1983; and Bowen, 1981).

In a survey of direct filtration plants (Letterman and Logsdon 1976), dual media filters consist of a sand layer varying from 15 to 38 cm with an effective size of 0.46 mm, and a coal layer of 35 to 50 cm with an effective size of 0.98 mm. Hutchison (1976) found that on dual media filters the effluent turbidity was not a function of the effective size of the coal within 0.9 to 1.55 mm. However, for the overall efficiency of the filter including effluent quality, length of filter run, and floc distribution within the filter, the best effective size for the coal was near 1.05 mm. McCormick and

King (1982) reported that a filter media configuration of 51 cm of 1.3 mm effective size coal and 25 cm of 0.45 mm effective size silica sand was more efficient than a dual media filter with 1.7 mm effective size or a mixed media filter with coal having an effective size of 1.0 mm (the sand effective size of 0.45 mm was not varied). This investigation is supported by Hutchison and Foley's (1974) earlier report that with coal of 1.7 mm effective size only 66 percent of the headloss took place in the coal layer forcing the floc to be stored in the sand layer which led to filter clogging and early turbidity breakthrough. For the coal layer with effective size of 1.3 mm, 92 percent of the head loss (and hence floc storage) occurred within the coal thus allowing longer filter runs.

In the studies conducted on mixed-media versus dual media for direct filtration, both types of media will produce an acceptable quality effluent (Culp, 1977, and Sequeira et al., 1983). Culp (1977) reported that mixed media filters have the advantage of providing greater storage for floc in the bed, thus increasing the length of filter runs; whereas dual media beds exhibit rapid increases in head loss and shorter filter runs. Sequeria et al. (1983, p. 78) reported, "mixed media provides greater health protection as demonstrated by its better resistance to bacterial and turbidity breakthrough." They also found that after backwashing, mixed media filters take less time to recover and produce good effluent turbidities than dual media filters. Although these studies indicate mixed media filters are more efficient than dual media filters, the dual media filter bed is more economical and can produce an acceptable finished water.

Comparing head loss characteristics for different filter media, Tate et al. (1977) found a consistent pattern indicating an increase in initial head loss with decreasing size of the bottom media and an increase in the head loss accumulation rate for smaller bottom media. Their studies were conducted on media configurations that had bottom layers of sand or garnet with effective sizes in the range of 0.21 to 0.5 mm, with the 0.5 mm sand performing the best. Monscivitz et al. (1978) varied the effective size of the coal layer from 0.70 mm to 0.95 mm in their dual media filters to determine its effect on filter performance. They found that a coal medium with an effective size of 0.95 mm produced a more uniform head loss across the coal-sand media than the 0.70 mm coal medium.

Hutchison and Foley (1974) investigated the effect of media size on filter performance in relation to the depth of media (18 inches and 12 inches) and filtration rate (3.1 gpm/sq. ft. and 4.8 gpm/sq. ft.). At a filtration rate of 3.1 gpm/sq. ft., the 18 inch depth of coal exhibited a 60 percent increase in the total water filtered per filter run as compared to the 12 inch depth of coal. At the rate of 4.8 gpm/sq. ft., the gross water production for the 18 inch depth of coal was 100 percent higher than for the 12 inch depth of coal. Kawamura (1975) in studies of different sizes and depth of filter media reestablished the relationship that media depth for small size media can be less than for large size media. This relationship reiterates the importance of total available surface area of media grains of the filter bed.

Filter rates

The Direct Filtration Committee (1980) reported that the majority of the filtration rates for operating treatment plants range from 1 to 6 gpm/sq. ft. (0.7 to 4.1 mm/s). Filter run times of up to 4 to 5 days have been achieved at the lower rates. Turbidity breakthrough is the problem most associated with higher rates (up to 10 gpm/sq. ft). The Committee (1980) stated that filtration rate is not the most crucial parameter in controlling the filter run times, but rather proper coagulant dosage and/or diatom algae concentrations.

Westerhoff et al. (1980) compared direct filtration versus conventional treatment and found filtration rates of 2 to 6 gpm/sq. ft. (0.7 to 4.1 mm/s) for the direct filtration system produced filtered water with a turbidity of 0.1 to 0.3 TU which was comparable to that produced by conventional treatment. During the Westerhoff et al. (1980) testing period, raw water turbidities varied from 1 to 100 TU. Wagner and Hudson (1982) found that several waters pilot-tested have been successfully treated at filtration rates of 5 to 15 gpm/sq. ft. (3.5 to 10 mm/s). Among these was the pilot plant testing at the Skinner Water Treatment Plant of the Metropolitan Water District of Southern California where the pilot filters were operated at 15 gpm/sq. ft. During the several months of testing, the raw water turbidity averaged 2.1 NTU, and the effluent turbidity was 0.3 NTU or below. Another example cited by Wagner and Hudson (1982) was the pilot studies conducted on the Owens River water by the Los Angeles Department of Water and Power. Direct filtration rates of 10 and 15 gpm/sq. ft. (7 and 10 mm/s) successfully treated the Owens River water to California's 0.5 NTU limit with filter runs between 10 and 12 hours. Pilot studies conducted in Brazil (Wagner and Hudson, 1982) indicated successful operation at a filter rate of 7.8 gpm/sq. ft. (5.2 mm/s) for average raw water turbidities of 25 NTU, and a maximum of 48 NTU. The average filter run time for this study was 15 hours.

In Tredgett's (1974) summary of direct filtration pilot studies conducted on Lake Ontario water, a normal operating filtration rate of 4.8 gpm/sq. ft. was optimum for raw water turbidities of less than 13 Jackson turbidity units (JTU). At this rate filter runs were in the range of 20 to 40 hours. A peak filter rate of 8 gpm/sq. ft. was also successful with filter runs of 10 to 30 hours. During the peak rate at raw water turbidities of 13 to 43 JTU, filter runs of 8 to 15 hours could be achieved with effluent turbidities of 0.2 JTU. Trussell et al. (1980) summarized the impact of filtration rate on effluent turbidity in three different pilot studies where filtration rates ranged from 3 gpm/sq. ft. to 18 gpm/sq. ft. and indicated that filtration rate had little to no impact on the effluent turbidity for this range.

The optimum filtration rate is raw water quality dependent. Rates of 8 gpm/sq. ft. or greater are possible mainly because of favorable raw water conditions and proper pretreatment. Operational problems caused by raw water conditions become more pronounced as the filtration rate increases (Hutchison, 1976). Further, increased filtration rates require a higher degree of plant operator vigilance and increased instrumentation. Filter run length is partially dependent on filtration rate. Generally as the rate is increased filter run time is decreased. Other parameters affecting the filter run time include raw water color, turbidity (alum dosage), algae, mixing energy for floc formation, and filter media. Changing any one of these parameters will result in a change in filter run characteristics.

The Committee Report (1980) indicated that the majority of the direct filtration plants operate at a constant rate rather than a declining rate mode. Little research has been conducted in the area of declining rate filtration, but the pilot studies that have been conducted (Committee Report 1980) indicated that little effluent quality advantage was achieved by operating a filter at a declining rate.

Filter wash

A major difference in the operation of a conventional treatment system and a direct filtration system is the volume of wash water required for backwashing.

In conventional treatment a settleable-floc is produced in the coagulation-flocculation process. This floc is then removed in the settling basins. The filters in conventional treatment serve primarily as a polishing process with few solids stored within the filter. Thus, conventional treatment wash water requirements are generally less than 2 percent of the total volume of water treated (McCormick and King, 1982). In direct filtration all solids removed from the water are stored within the filter media, ultimately increasing the volume of wash water required and decreasing the filter run times. Culp (1977) reported that wash water requirements can economically only be as high as 6 percent of the total water produced by a direct filtration system. Hutchison (1976) reported that 5 percent or less of the total volume of water produced was a feasible volume of wash water needed for backwashing the Ontario direct filtration plant. However when high diatom levels are present, as was the case for the Toronto plant, as much as 27 percent of the total treated water was required for backwashing the filters (Hutchison and Foley, 1974).

Filters are backwashed when the head loss across the filter reaches a predetermined value (8-10 ft.) or when turbidity breakthrough occurs. Occasionally filter runs are terminated prior to either of these, simply because they have reached a set maximum number of hours before backwashing is required. Backwashing is performed by reversing the flow of water such that it moves upward fluidizing the filter media bed. Fluidization occurs at the critical velocity of the individual media particles. As the velocity of the wash water increases beyond the critical velocity, the particles become more widely separated and travel in an unhindered manner. During the bed expansion the particles trapped during the filtration process are freed from the media particles by the shearing action of the wash water or the abrasive action of the contact with other rising bed particles. The waste solids and wash water are then treated for reuse in the plant with appropriate sludge handling. Kawamura (1976) stated that the use of polymers as primary coagulants or coagulant aids reduces sludge volume and improves subsequent sludge dewatering.

The rate of backwash is media size and distribution dependent. The ultimate goal in backwashing is sufficient media bed expansion such that trapped waste solids are freed from the media while using the smallest volume of wash water possible. One operating parameter for backwash that was typical of the literature reviewed was the cleaning of the filter surface by surface wash or air scour prior to commencing backwash.

Air scour was found to be necessary for the prevention of mudball formation and algal growth in the Ontario direct filtration plant (Hutchison 1976). The Committee Report (1980) further states that cleaning the filter by air-scour prior to backwashing has been successful in reducing the volume of wash water required.

A recent development in backwashing has been the introduction of an appropriate polymer in the clear water used for backwashing. According to Yapijakis (1982), by adding a polymer to the backwash water it was possible to simultaneously condition the filter bed, reduce the initial turbidity breakthrough duration and peak, and improve the settling ability and consequent sludge thickening of the backwash solids. This procedure provides both economic and operational advantages in the direct filtration process compared with adding polymers separately for each purpose.

Advantages and Disadvantages

The principal attraction of direct filtration is the potential capital savings of up to 30 percent of the cost of conventional treatment systems (Culp, 1977, and Tate et al., 1977). Similar savings are realized in the operation and maintenance of direct filtration facilities. The savings in capital cost result from elimination of the sedimentation basins and the sludge-collection equipment, which cuts down not only on construction costs but also the land required for the treatment plant. When applicable, some direct filtration facilities incur even greater capital savings by eliminating the flocculation process.

Operation and maintenance costs are reduced because there is less equipment to maintain and less chemical requirements. In direct filtration a filterable floc is desired rather than a settleable floc. To achieve this type of floc less alum is required. Culp (1977) reports that the costs for polymer may be greater than in conventional plants, but these higher costs are more than offset by the lower costs for coagulants with savings of 10 to 30 percent. The decrease in chemical coagulant dosages further results in decreased sludge production and maintenance.

Westerhoff et al. (1980) reported that the direct filtration process can consistently produce high quality filtered water with significant annual operating cost advantages of about $50,000 for the present (1980) plant production, not including the savings incurred in less sludge treatment and disposal costs. The City of Springfield, Massachusetts, experienced a 43 percent savings with construction of its 60 mgd direct filtration addition opposed to expanding its conventional treatment plant facility (Willis, 1972). After two years of operation of the Bella Vista Water District direct filtration facility in North Central California, Chapman and Benoit (1980, p. 104) report "low operation and maintenance costs, in addition to the low capital cost, have made the system (direct filtration) cost-efficient, with minimum labor, power, chemical and required maintenance expenditures." The Direct Filtration Pilot Plant studies for Croton, New York, proved to be well worthwhile by indicating a potential savings of $14 million, the difference between the construction cost of direct filtration and optimized conventional treatment (Fulton, 1980). Logsdon et al. (1980) present an excellent analysis method for the comparison of costs and capabilities of direct filtration and conventional treatment based on varying construction costs and operation and maintenance costs.

The limitation to direct filtration is the ability to handle high concentrations of suspended solids. Direct filtration may not be applicable for raw waters with high turbidities (>200 TU), color greater than 100 units, or plankton exceeding 2000 ASU/ml. Another disadvantage of direct filtration is shorter filter runs compared to conventional systems. Culp (1977) reports the cost consequence of this is not significant, but that more operator vigilance is required, increasing the chance of operation error. Wash water requirement in direct filtration plants is another disadvantage. Requirements may be as high as 6 percent if not greater compared to the average 2 percent required for conventional treatment of similar raw water. Culp (1977) reports that this difference is not significant in the overall treatment plant operating costs.

The overall potential of economy, both in capital outlay and operating costs, make direct filtration attractive. This is especially true for communities whose water supplies were potable with little or no treatment other than disinfection but must now further treat to comply with the 1 NTU limit of the EPA National Interim Primary Drinking Water Regulation. By using direct filtration, communities can meet the more stringent turbidity limit at a cost substantially less than that of a conventional treatment system. Direct filtration can also make an important contribution to drinking water safety in developing countries with limited financial resources.

RESEARCH METHODOLOGY

To achieve the objectives of this research project the investigation was divided into two phases; phase I the evaluation by statistical comparison of treated effluents of an online direct filtration facility and a conventional treatment facility, and phase II the construction and operation of a pilot scale direct filtration system.

Comparison of Treated Effluents

In order to analyze the quality of the product water of an on line direct filtration facility, the effluents of an operating conventional treatment facility and an operating direct filtration plant treating comparable waters were compared through statistical testing for significant differences. The Metropolitan Water District of Salt Lake City, Little Cottonwood Water Treatment Plant (LCWTP) and the Utah Valley Water Purification Plant (UVWPP) (direct filtration) were the two treatment plants chosen for comparison. The Little Cottonwood Treatment Plant receives approximately 65 percent of its source water from Deer Creek Reservoir whereas the Utah Valley water plant treats only Deer Creek Reservoir water.

Little Cottonwood Water Treatment Plant

The Little Cottonwood plant is a conventional water treatment plant located at the base of Little Cottonwood Canyon in Salt Lake County. This 102 mgd plant is a major supplier of water to Salt Lake City and County. The plant receives water from two sources, Little Cottonwood Creek and Deer Creek Reservoir. Deer Creek Reservoir supplies about 65 percent of the water treated annually with the largest withdrawals occurring in the winter, summer, and fall seasons. The water from Deer Creek Reservoir is delivered via a 32 mile long reinforced concrete aqueduct. The raw water from Deer Creek is normally treated at the reservoir outlet with 0.5 mg/l chlorine to control bacterial growth during transport.

The Little Cottonwood Water Treatment Plant employs the conventional treatment processes shown schematically on Figure 7. Potassium permanganate ($KMnO_4$) is added at the raw water intake for taste and odor control and aeration basins are used prior to the rapid mix. Alum is the primary coagulant, added to the rapid mix with silica as the coagulant aid most generally used at the plant. Lime is also added at varying dosages for pH and corrosion control.

Minor amounts of chlorine are added at the rapid mix to control algal and bacterial growth during treatment, and post chlorination is used prior to filtration to maintain a residual. During the period of this research (August 1980 - August 1983), the filters consisted of 24 inches of sand supported by gravel. In 1984 the Little Cottonwood treatment plant converted to a mixed bed media of anthracite, sand and gravel. Thus current filter characteristics and finished water data at the Little Cottonwood plant may not correlate with those used in this study.

Utah Valley Water Purification Plant

The Utah Valley Water Purification Plant is a 42 mgd direct filtration

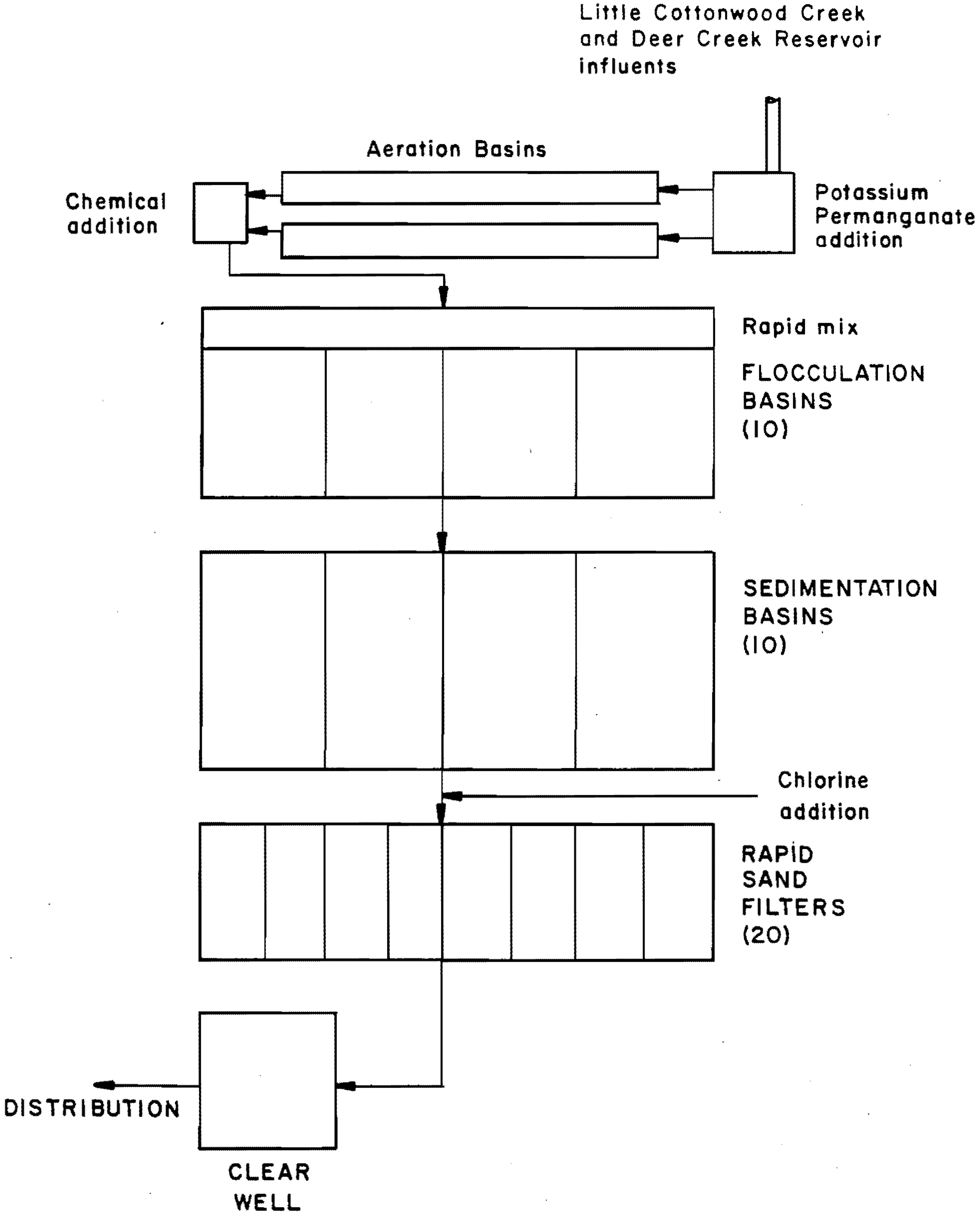


Figure 7. Schematic of processes for the Little Cottonwood Water Treatment Plant.

facility located at the mouth of Provo Canyon in Orem, Utah. This plant serves the urban areas of Central Utah by treating water from Deer Creek Reservoir. The water travels from the reservoir in the same aqueduct that is supplying the Little Cottonwood Treatment Plant. The water travels 10.1 miles to the Utah Valley plant, where water is withdrawn, with the remainder traveling on to the Little Cottonwood plant.

As shown in Figure 8, the direct filtration treatment begins with the addition of $KMnO_4$ for taste and odor control. It is followed by coagulant addition at the rapid mix unit. The major difference from the conventional treatment plant at Little Cottonwood is elimination of the sedimentation basins. After flocculation the water travels directly to dual media filters, 20 inches of anthracite coal and 10 inches of sand supported on an 18 inch gravel underdrain.

The primary coagulant used at the Utah Valley plant is alum with cationic polymers added as coagulant aids during the high turbidity season. When necessary, the pH is controlled by the addition of caustic soda. Disinfection is accomplished by post-chlorination after filtration and just prior to discharge of the water into the reservoir and distribution system.

Data for analysis

The Utah Valley Purification Plant was placed online in the spring of 1979, and the Little Cottonwood Treatment Plant has been operated for the past 23 years. To allow a one-year period for correcting initial operating difficulties at the Utah Valley plant, the water quality data prior to August 1980 were not used in comparing the two treatment facilities. Thus, data log sheets from August 1, 1980, through August 31, 1983, were obtained for both the Utah Valley and Little Cottonwood treatment plants. A representative data sheet from each treatment facility is in Appendix A.

The parameters chosen for comparisons were total daily flow, raw water turbidity, effluent turbidity, effluent chlorine residual, raw water pH, effluent pH, finished water temperature, and alum and $KMnO_4$ dosing concentrations. These parameters where chosen, because not only are they common to both treatment facilities, but the treatment processes of coagulation and flocculation are dependent on turbidity, pH, temperature, and chemical dosing. In addition to this finished water turbidity has historically been the parameter for evaluating the quality of the product water. These were available from the sample data sheets on a daily basis for a total of 1055 days of data for the Little Cottonwood plant and 1044 days for the Utah Valley plant (periodically data were missing from the log sheets).

Data were entered into computer storage for each parameter aforementioned for each day between August 1, 1980, and August 31, 1983, for both locations. Listings of the data were checked for any discrepancy from the original log sheets. Following entry, the data from Little Cottonwood Treatment Plant were matched with those from the Utah Valley Treatment Plant on a day-to-day basis. At this time, any difference in the units for a parameter between the two treatment plants were corrected (e.g., temperatures were converted °C, total flows to mgd, etc.). The matching procedure also involved the elimination of any day that had missing data from either treatment plant for any one of the parameters under investigation. This procedure gave 509 days of matched data. Days missing in the matched data set appeared random. Adjustments to the Little Cottonwood data were necessary because of the two different source waters. The total flow was taken as the sum of the Deer Creek water and the Little

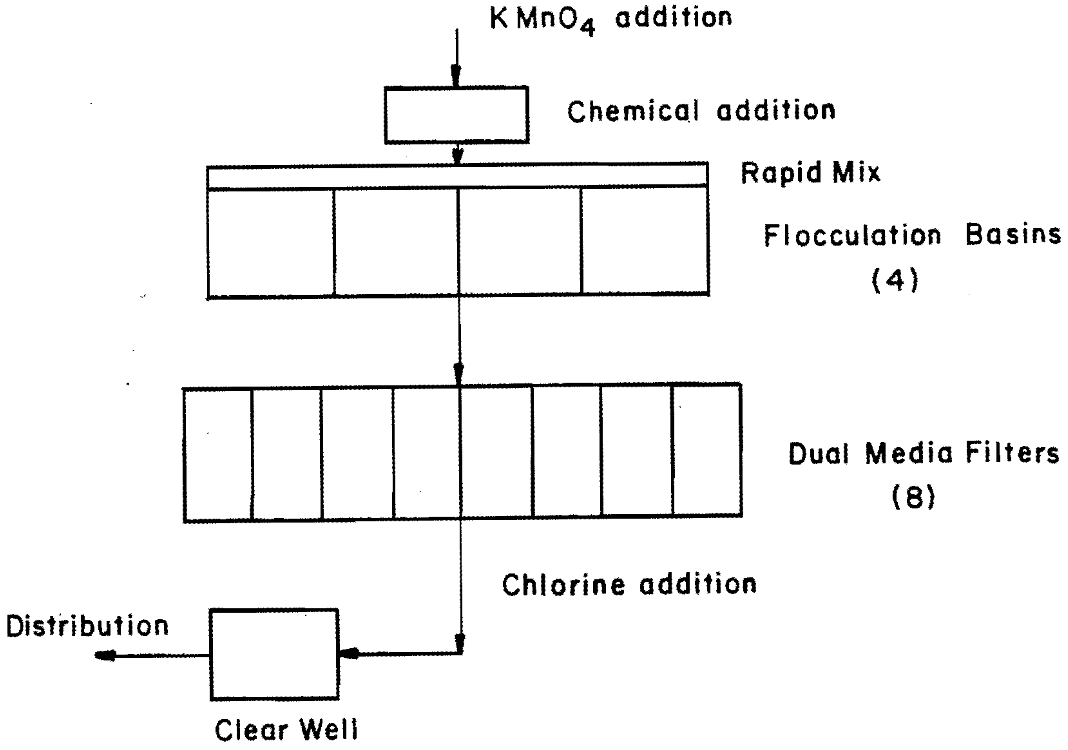


Figure 8. Schematic of processes for the Utah Valley Water Purification Plant.

Cottonwood Creek water treated at the plant. A weighted average was used in estimating the raw water turbidity and pH because the waters from the two sources are mixed prior to treatment.

Using the matched set of data several different statistical methods were tried for some type of correlation between the two treatment plants. The statistical methods included a listing of the mean, standard deviation, maximum, and minimum for each designated parameter and each treatment plant. Finally the matched data sets were examined by the t-test for significant differences of the parameters.

Review of these comparative statistics suggested that the large sample size created abnormally high statistical precision when the mean values showed little descrepancy. The sample size was thus segmented into smaller groups such that a "practical" statistical comparison could be achieved (Sisson, 1984).

Reduction of the sample size was achieved by grouping the data into four seasons, with winter including November, December, and January, spring including February, March, and April, summer including May, June, and July, and fall including August, September, and October. The months placed in each season were selected from sequential plots for raw water turbidity where a cyclic pattern was seen.

The total, rather than just the matched data were used for the seasonal comparisons. This was accomplished by including any measured parameter for days that had been eliminated because one or more parameters were missing. A package statistical program (Minitab) from Penn State University was used to determine the seasonal means, standard deviations, and sample sizes for each parameter and location.

The seasonal data were examined for significant difference by an F-distribution based on a two-way analysis of variance. In the data, there were possible variations in location (e.g., Little Cottonwood vs. Utah Valley) and in season. An F-ratio, which is the mean square of the variation in the data associated with location (or season) divided by the mean square, is used as the reference to indicate significance.

Pilot Scale Direct Filtration System

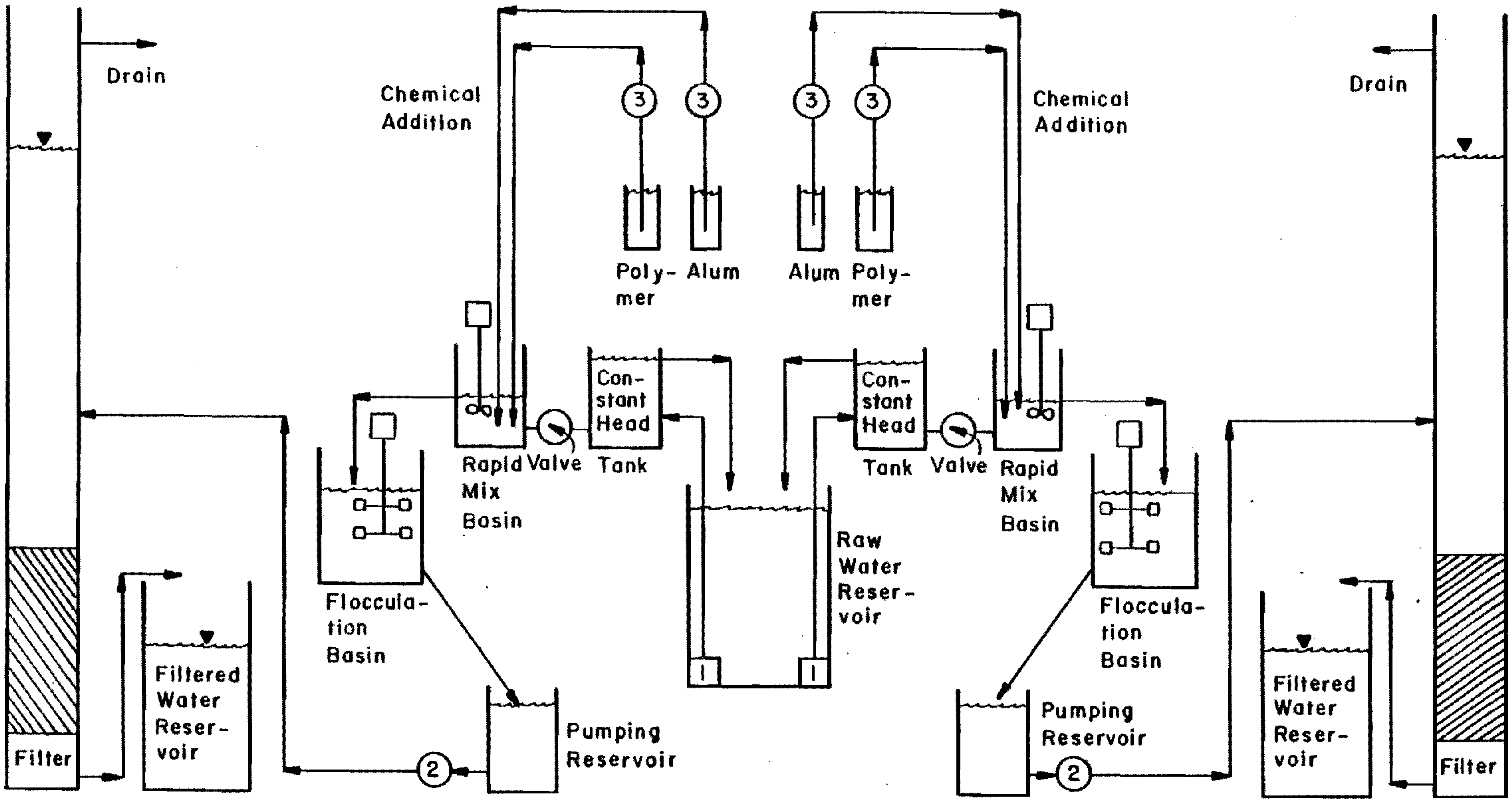
Duplicate pilot-scale direct filtration water treatment plants were constructed following the flow scheme of Figure 9. Duplicate systems were used such that one system could be used as a control during data collection. The pilot plants were set up and operated at the Utah Valley Water Purification Plant in Orem, Utah. This, enabled the pilot plant to treat the same source water as the full-scale, operating direct filtration facility. The parameters under evaluation included raw water characteristics (i.e., temperature, pH, and turbidity), coagulant type and dosage, filter loading rates, and effluent quality (i.e., temperature, pH, and turbidity).

The raw water reservoir was a 208 ℓ (55 gallon) barrel, teflon coated to inhibit rust. A submersible pump, suitable to pump in excess of 30 gph, was used to pump water from the raw water reservoir to the constant head tank. The constant head tank was a 13 ℓ (3.4 gallon) acrylic cylinder with inlet, outlet, and overflow port of 1 cm (1/2 inch) acrylic tubing. The raw water flowed from the constant head tank to a 13 ℓ (3.4 gallon) acrylic rapid mix basin through 1/2 inch ID Tygon tubing. Filter flow rates were controlled by using a semi-globe ballcock valve on the Tygon tubing. Coagulation chemicals, alum, and polymer, were added to the rapid mix basin by two polystaltic, chemical feed pumps. From the rapid mix basin the chemically treated water flowed by gravity into a 47 ℓ (12.4 gallon) plastic flocculation basin. The design velocity gradient for the flocculator was 42 s^{-1} which is in the typical range of 20 s^{-1} to 60 s^{-1} cited in the literature. The detention times for the rapid mix basin and the flocculation basin were dependent upon the filter loading rate as presented in Table 3.

Following flocculation the water flowed by gravity into a 19 ℓ (5 gallon) plastic pumping reservoir. The pumping reservoir was used as a control for assuring a constant filter loading rate. This was achieved by maintaining a constant water level in the reservoir once the system had established equilibrium. The water was pumped from the pumping reservoir to the filter unit by a Cole-Parmer Masterflex, variable-speed, peristaltic pump. The filter unit was made of 10.8 cm (4 1/4 inch) ID acrylic tubing lengths that were joined together by sealed, bolted flanged connections. Flow through the filter was controlled by an airbreak located on the effluent line, level to the filter media surface and by the application of a constant flow rate to the filter. As headloss across the filter accumulated, the water level in the filter increased sufficiently to maintain a constant effluent flow rate. The construction details of the constant head tank, rapid mix basin, flocculation basin, flocculation paddles, and filter unit

Table 3. Detention times for rapid mix and flocculation basins.

Filter loading rate gpm/ft^2	Detention time (minutes) Rapid Mix	Detention time (minutes) Flocculator
3	2.8	42.0
4	2.1	31.5
5	1.7	25.2



LEGEND

1. Submersible Pump
2. Variable-speed Peristaltic Pump
3. Polystaltic Chemical Feed Pumps

Figure 9. Pilot plant flow scheme.

are illustrated in Figure 10. Figures 11 and 12 represent the support stand and the flow of the system once completely set-up.

It was decided that since the pilot plant was treating the same source water as the Utah Valley direct filtration plant, the filter media used in the pilot study should have the same specifications as that of the Utah Valley Plant. Starting from the bottom of the filter unit to the top, the media had the following characteristics:

GRAVEL SUPPORT

Layer No.	Passing Screen Size	Retained Screen Size	Depth
1	1-1/2 inch diameter	3/4 inch diameter	6 inch
2	34 inch diameter	1/2 inch diameter	3 inch
3	1/2 inch diameter	1/4 inch diameter	3 inch
4	1/4 inch diameter	No. 6 sieve	3 inch
5	No. 6 sieve	No. 14 sieve	3 inch
		Total:	18 inch

SAND LAYER

Effective Size	Uniformity Coefficient	Depth
0.34 mm	1.38	10 inch

ANTHRACITE COAL LAYER

Effective Size	Uniformity Coefficient	Depth
1.02 mm	1.23	20 inch

The initial headloss across the filter media as calculated by the Rose equation (Clark, et al., 1977) for stratified beds with uniform porosity is 4.1 inches for the anthracite coal layer and 29.4 inches for the sand layer. These values are based on the coal porosity of 0.47 and the sand porosity of 0.38. The theoretical detention time in the filter column, assuming a clean filter bed and a total initial headloss of 33.5 inches, is 7.5 minutes at 5 gpm/ft2, 9.4 minutes at 4 gpm/ft2, and 12.5 minutes for 3 gpm/ft2.

The filtered water was collected in a 208 ℓ (55 gallon) teflon lined barrel for backwashing. The filters were backwashed at the end of each testing period which was generally characterized by terminal headloss of 8 feet across the filter or turbidity breakthrough of 1 NTU. A back wash rate of 22.4 gpm/ft2 was used for 7 minutes once the filter bed had expanded 50 percent. This rate corresponds to the Utah Valley media specifications for 50 percent media expansion. A minimum of 2 minutes was allowed for bed expansion, during which time the filter column was manually vibrated to eliminate cohesion of media particles to the side walls of the column. The total volume of wash water used for the back wash process was

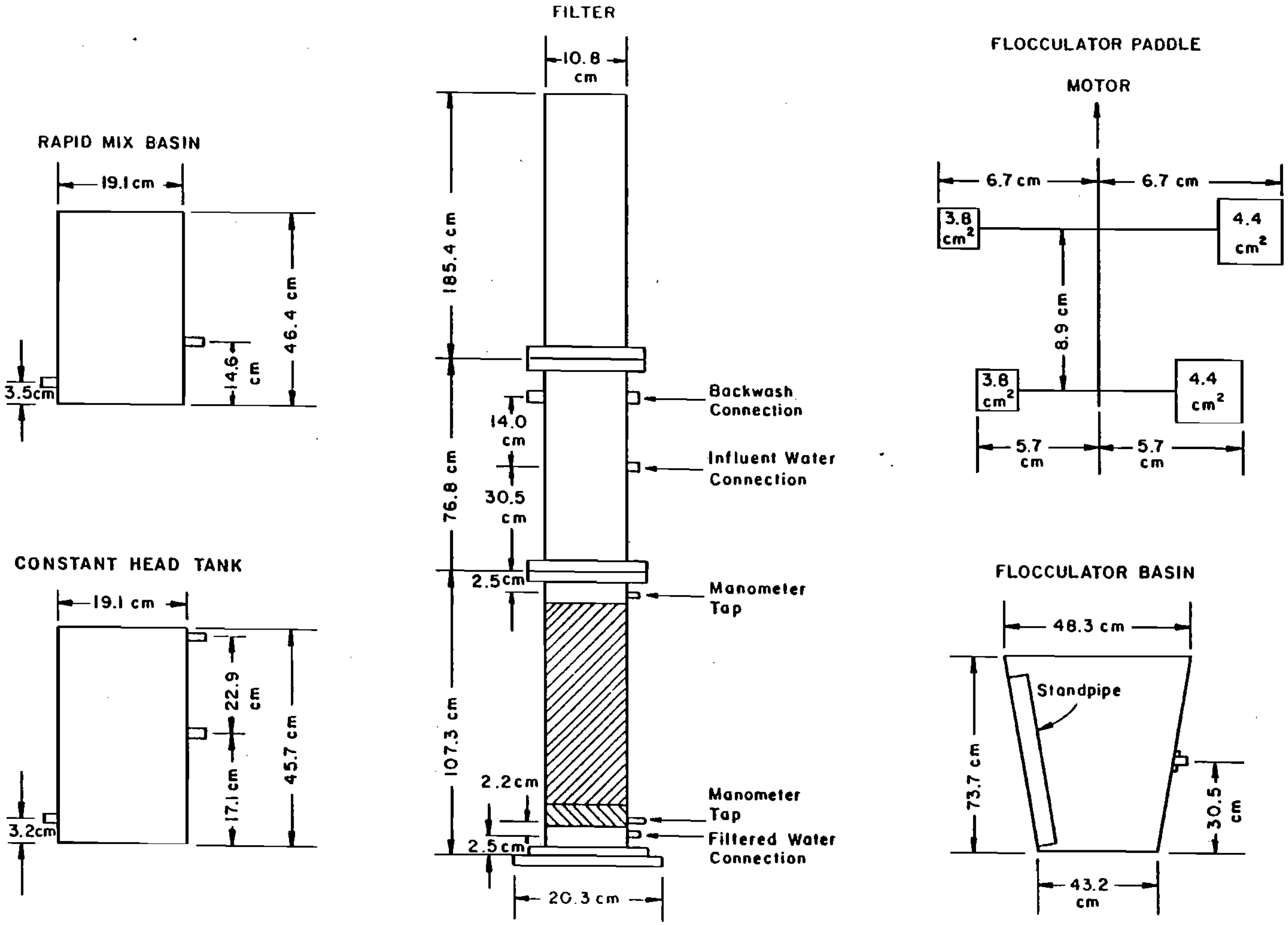


Figure 10. Construction details for pilot plant.

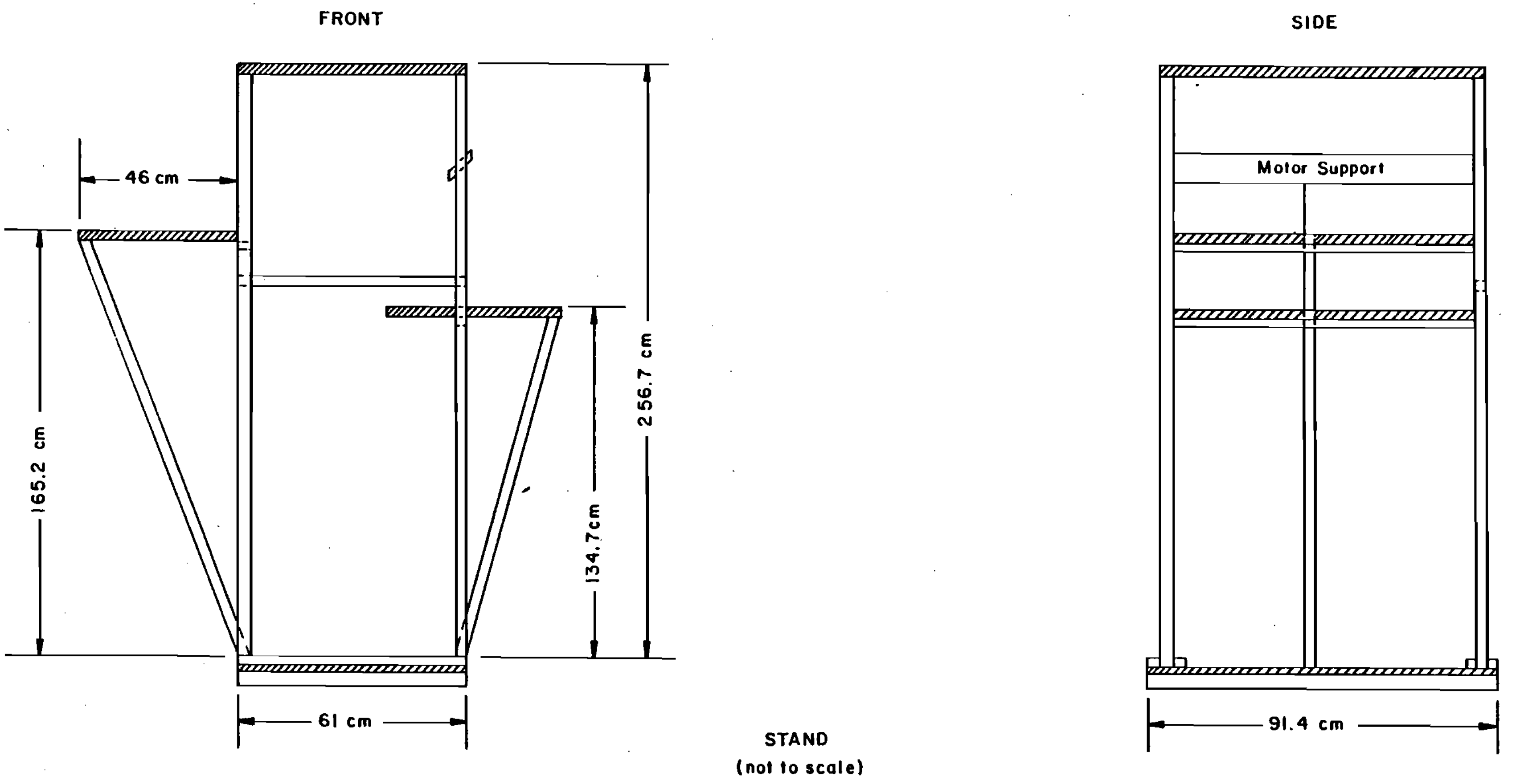


Figure 11. Support stand for pilot plant.

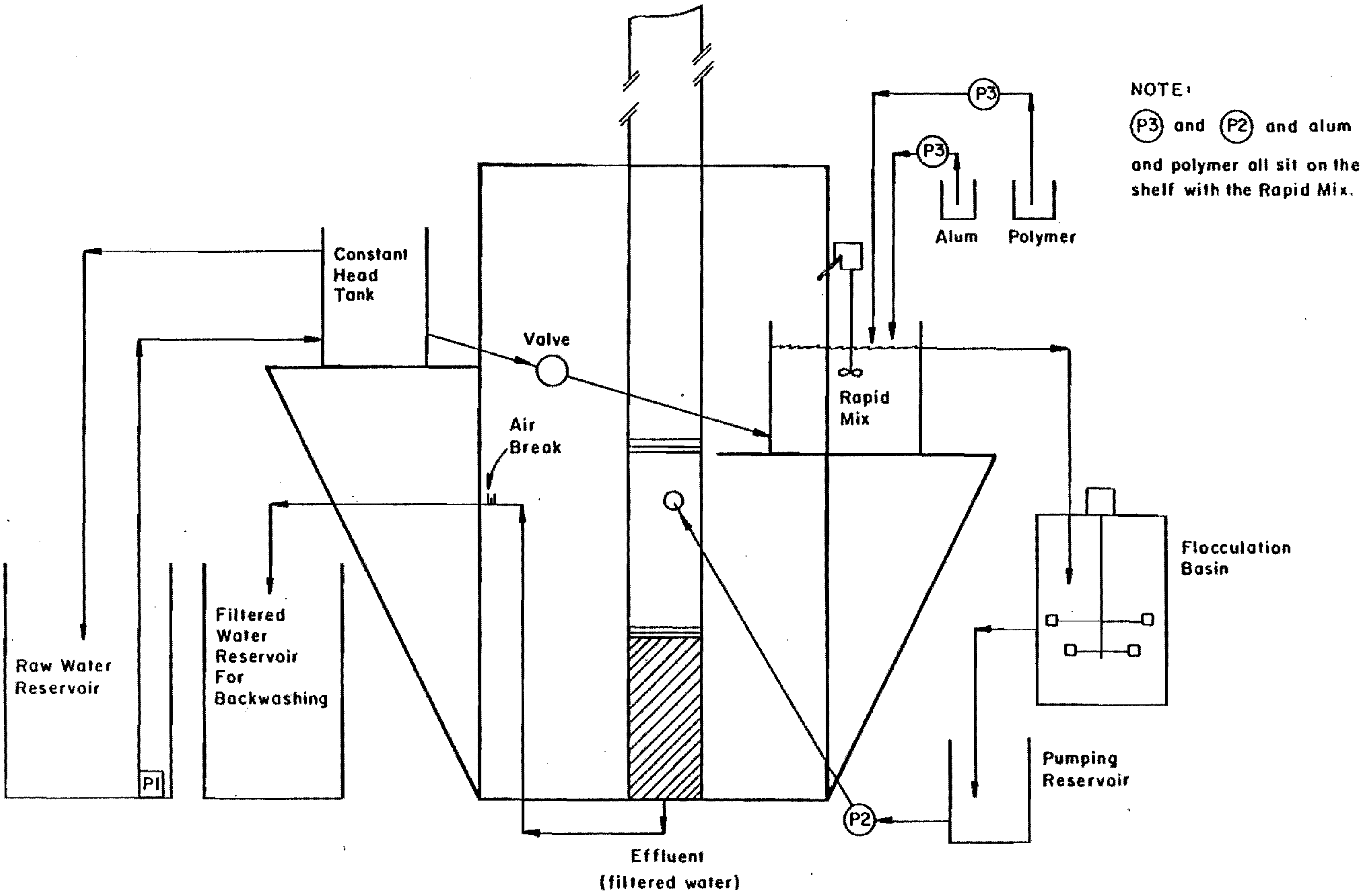


Figure 12. Flow diagram of complete system set up.

less than 30 gallons. This volume of water sufficiently cleaned the filter bed and allowed for proper media separation and settling.

Operating parameters

The parameters that were varied during this study included filter loading rate from 3 gpm/ft^2 to 5 gpm/ft^2 and the use of coagulation chemicals and their dosages. The choice of filter loading rates was on the general operating rate (<5 gpm/ft^2) and the design rate (5 gpm/ft^2) of the Utah Valley plant. Different tests of the pilot plant consisted of water treatment without coagulants, alum (6.8-20 mg/l) as the only coagulant, and alum (2.14-9.40 mg/l) as the primary coagulant with T-chem 512 a cationic polymer (0.28-1.54 mg/l) as a coagulant aid. Some of the testing periods included the addition of potassium permanganate ($KMnO_4$) at the raw water reservoir. $KMnO_4$ was added in doses of 0.3 to 0.6 mg/l primarily for taste and odor control. However, after approximately 4 hours of filter run time a pink tint, characteristic of $KMnO_4$, was visible in the effluent water. Because of the $KMnO_4$ interference in the effluent water and the overall objective of the pilot plant being the determination of efficient coagulant combinations and doses for turbidity removal, use of $KMnO_4$ for taste and odor control was discontinued.

The aforementioned chemical doses were not necessarily the target doses, but rather the average chemical dose for the testing period. The average dose was obtained by knowing the initial and final volume of the chemicals during the testing period and the assumption that the chemical feed pumps pumped at the constant rate they were calibrated to at the beginning of each testing period. It was necessary to make this assumption, because once the pilot plant system was in operation and chemicals were being added, any interruption to the system for recalibration would have resulted in a shock to the system resulting in conflicting data. Prior to each testing period the tubing in the chemical feed pumps and the Cole-Parmer peristaltic pumps was replaced. At this time the pumps were also calibrated to the desired flow rates.

A problem encountered after shutdown of the pilot plant was entrapped air in the filter media. The air in the filters was a result of the solubility of dissolved oxygen decreasing as the temperature of the water remaining in the filter media increased to ambient temperature. The oxygen released during temperature equilibration caused air voids in the filter media, resulting in an initial headloss across the filter greater than 33.5 inches. In order to release the air prior to the next testing period it was necessary to back wash and manually vibrate the filters. This back wash procedure was in addition to the normal operating back wash stage. During this back washing the filter column was not allowed to drain until the entire pilot plant system was in full operation.

The performance of the pilot plant was assessed by raw water characteristics (temperature, pH, and turbidity), headloss buildup across the filter, volume of water produced and effluent quality (temperature, pH, and turbidity). Data for these parameters were not collected until flow equilibrium for the system was established, generally 1 hour after plant start-up. All analytical testing that was performed to characterize the system was in accordance with Standard Methods (APHA, 1980).

RESULTS AND DISCUSSION

The discussion of the results for the statistical comparison of the treated effluents and the performance of the pilot scale direct filtration system shall be treated separately.

Comparison of Treated Effluents

The statistics computed from the 509 days of matched data are shown in Table 4 (UVWPP) and Table 5 (LCWTP). The first parameter to consider in comparing the conventional treatment plant and the direct filtration plant is finished water turbidity. According to the literature reviewed, finished water turbidity has typically been the main criterion for evaluating the quality of water for operating and pilot-scale direct filtration plants. As seen from Tables 4 and 5, the mean finished water turbidity for both the Utah Valley Water Purification Plant and the Little Cottonwood Treatment Plant is below the EPA Primary Drinking Water Regulation of a maximum contaminant level of 1 TU.

A t-distribution test (Ott, 1977, and Huntsburger and Billingsley, 1977) was conducted to examine the significance of any difference in the finished water turbidity for the matched data means. The rejection region for the t-test of equality of means is specified by the inequality

$$t > t_{\alpha,n-1},$$

where

$$t = \frac{Y_1 - Y_2}{\sqrt{sp^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \qquad (1)$$

and Y_1 = mean value for location 1
Y_2 = mean value for location 2
n_1 = sample size for location 1
n_2 = sample size for location 2
sp = the pooled standard deviation for locations 1 and 2.

The value for $t_{\alpha,n-1}$ at $\alpha = 0.05$ is between 1.645 and 1.661 for 509 degrees of freedom (sample size), and for $\alpha = 0.01$, $t_{\alpha,n-1}$ is between 2.326 and 2.358. The value calculated for the t statistic from the data on finished water turbidity was 5.2053. Since this value is larger than both $t_{\alpha,n-1}$, the t-test hypothesis was rejected. Although this difference in means is statistically significant, the measured mean finished water turbidities (Tables 4 and 5) show that the difference between the treatment plants is too small to have a practical impact in achieving the turbidity standard.

The results of the two-way analysis of variance testing for differences among the means of the parameters for each location based on the seasonal data are presented in Table 6. The two-way analysis of variance of all available data was approached in three different fashions. As seen in Appendix B, Tables 12-18, seasonal values for the mean, standard deviation, and sample size of each parameter under investigation for both treatment plants were available for use in the analysis. An analysis of variance using strictly the mean values for each location, with the block being the seasons, proved to be the simplest method. An analysis of variance was also tried by weighting the means with the standard deviation in one instance and the sample size in another. This method was somewhat more complex with

Table 4. Statistics* for the direct filtration Utah Valley Water Purification Plant-based the matched set of data.

	Total Flow (MGD)	Raw Turb. (NTU)	Fin. Turb. (NTU)	Fin. Cl Residual MG/l	Raw pH	Fin. pH	Water Temp. °C	Alum Dose MG/l	$KMnO_4$ Dose MG/l
Mean	7.37	3.54	0.1649	0.6891	7.9697	7.8609	10.38	11.72	0.244
Std. Deviation	2.79	3.95	0.1806	0.2417	0.2085	0.1811	5.22	4.75	0.521
Maximum	14.82	26.00	1.7000	3.0700	8.6000	8.4000	20.30	34.00	4.500
Minimum	1.72	0.70	0.0200	0.1200	7.4000	7.3000	4.00	0.00	0.000

* Values taken from computer.

Table 5. Statistics* for the Little Cottonwood Water Treatment Plant - based on the matched set of data.

	Total Flow (MGD)	Raw Turb. (NTU)	Fin. Turb. (NTU)	Fin. Cl Residual MG/l	Raw pH	Fin. pH	Water Temp. °C	Alum Dose MG/l	$KMnO_4$ Dose MG/l
Mean	43.57	2.11	0.1204	1.0161	7.7543	8.072	7.85	22.89	0.184
Std. Deviation	28.3	2.48	0.0684	0.2127	0.2201	0.263	3.78	5.19	0.234
Maximum	120.0	17.03	0.5300	2.7200	8.2500	9.370	16.67	35.00	0.990
Minimum	12.0	0.21	0.0200	0.6900	6.8500	7.290	3.89	6.00	0.000

* Values taken from computer.

Table 6. Analysis-of-variance comparing the Little Cottonwood Water Treatment Plant and the Utah Valley Water Purification Plant--based on seasonal data.

	Mean		Significance		Probability of a Larger F
	Little Cottonwood	Utah Valley	* = 0.05	* = 0.01	
Total Flow	41.0	7.2	S.	S.	<0.005
Raw Turb. (NTU)	2.2	3.7	S.	S.	<0.005
Fin. Turb. (NTU)	0.12	1.20	N.S.	N.S.	0.98
Raw pH	7.8	8.0	S.	S.	<0.005
Fin. pH	8.0	7.9	S.	S.	0.007
Water Temp °C	8.2	10.6	S.	S.	<0.005
Alum Dose (mg/l)	21.8	12.4	S.	S.	<0.005

*N.S. = Not significantly different.
S. = Significant difference.

results not significantly different than those obtained by use of the means alone. Thus the F-ratio presented in Table 6 and the data in Table 19 were derived from the seasonal mean values of each parameter for both treatment plants. This technique is commonly referred to as an unweighted means analysis for disproportionate subclass numbers (Sisson, 1984).

As shown in Table 6, the two-way analysis of variance using an F-distribution indicates there is not a significant difference between the finished water turbidities for the Little Cottonwood treatment plant and the Utah Valley treatment plant.

For the turbidity data segregated by season, Table 7 shows that the Utah Valley plant consistently treats water of higher raw turbidity, with the greatest turbidity occurring during the fall months of August, September, and October. The high fall turbidity is no surprise because Deer Creek Reservoir, a eutrophic lake, characteristically turns over during this period. Although the turbidity is higher during this period, both plants produce a product water well below the maximum contaminant level of 1 TU specified by EPA.

The difference in raw water turbidity between the two plants may be attributed to two possible factors. Part of the raw water from Deer Creek Reservoir travels via the Salt Lake Aqueduct for 10.1 miles to the Utah Valley Plant, and then travels an additional 22 miles to the Little Cottonwood plant. The additional 22 miles allows opportunity for some of the particulate matter to settle within the aqueduct before it reaches the Little Cottonwood plant, thus lowering the raw turbidity.

The other contributing factor is the low turbidity of Little Cottonwood Creek. During the fall when the turbidity of Deer Creek reservoir is at its highest, Little Cottonwood Creek's turbidity is generally less than 0.2 NTU. It is also during the fall season that the relative volume of Little Cottonwood Creek water treated at the plant is greatest. The lower turbidity and higher volume of Little Cottonwood Creek water coupled with the particulate matter settling as the Deer Creek water travels through the aqueduct accounts for the lower raw water turbidity at the Little Cottonwood treatment plant.

The other water quality parameters investigated with the F-distribution all show a significant difference. It is obvious that a difference should be seen for the total flow considering the design capacity of the Little Cottonwood plant is 102 mgd and that of the Utah Valley plant is only 42 mgd. The important factor here is that both the Little Cottonwood and Utah Valley plants are treating volumes of water for which they were designed to treat, but less than their maximum capacities.

The difference between the raw water pH and the finished water pH for the two plants is significant statistically, but from a practical standpoint, a difference of 0.1 and 0.2 in the pH for the finished and raw water pH respectively, is not high. For the finished water, Little Cottonwood exhibits a pH of 8.0 and Utah Valley shows a pH of 7.9. According to Standard Methods (1980) ± 0.1 pH unit represents the limit of measurement accuracy under normal conditions. This difference cannot be considered significant from a practical viewpoint.

The difference in water temperature between the two plants is accounted for by the additional 22 miles the water travels underground in the Salt Lake Aqueduct to the Little Cottonwood plant. In the summer the water is cooled by the lower temperatures encountered below the ground surface, and the longer the water is underground the more time it has to equilibrate with the lower ground temperatures. The major temperature concern is the minimum temperature

Table 7. Mean seasonal turbidities for the Little Cottonwood Water Treatment Plant and the Utah Valley Water Purification Plant.

	Mean Raw Turbidity (NTU)		Mean Finished Turbidity (NTU)	
	Little Cottonwood	Utah Valley	Little Cottonwood	Utah Valley
Fall 80	4.78	6.66	0.11	0.36
Winter 80-81	0.85	1.69	0.08	0.14
Spring 81	0.93	1.60	0.09	0.22
Summer 81	1.49	1.64	0.14	0.01
Fall 81	4.78	8.71	0.17	0.13
Winter 81-82	0.82	2.16	0.10	0.07
Spring 82	0.60	1.99	0.14	0.09
Fall 82	3.66	8.28	0.11	0.29
Winter 82-83	0.69	2.84	0.10	0.24
Spring 83	2.86	3.09	0.15	0.18
August 83	3.87	5.84	0.15	0.60

encountered. Hutchison and Foley (1974) reported that at temperatures below 3.3°C there may be after-floc formation when using alum as the primary coagulant in direct filtration systems. The minimum water temperature of 4.0 °C (Table 4) approaches the level for after-floc formation, but does not go below. Low water temperatures can be handled in the direct filtration plants by increasing the detention time in the flocculators (Hutchison and Foley, 1974).

The other parameter investigated, alum dosing, is not compared meaningfully by the statistical analysis because of outside variables that affected it. Periodically, the treatment plants would use either cationic or anionic polymers as coagulant aids without a set pattern of dosing. Although alum was used by both plants as the primary coagulant, its dosing concentrations are directly related to the concentrations of polymer doses. Thus the erratic addition of polymers and not the effects of direct filtration accounts for the difference in amount of alum dosing.

Figures 13 through 18 provide pictorial representations of the seasonal differences in chosen parameters for the Little Cottonwood and Utah Valley treatment plants. The most apparent trend is the cyclic pattern in raw water quality among the seasons.

Pilot scale direct filtration system

The applicability, operation, and overall performance of a direct filtration water treatment system is dependent on the raw water characteristics. As seen in the literature reviewed, filter loading rates and types and dosages of coagulants vary with raw water characteristics. During the course of the pilot plant study the average raw water turbidity ranged from 2.7 NTU to 23.8 NTU. Being unable to hold the raw water turbidity as a constant parameter made it necessary to change coagulants and coagulant dosage as the raw water turbidity changed.

A summary of the performance of the pilot scale direct filtration system is presented in Table 8. All of the raw data collected during the pilot plant portion of the study is presented in Appendix C.

The overall performance of the filter columns was evaluated by the filter performance index (F.P.I.). Sequeria et al. (1983) defined the F.P.I. as a numerical method expressing the relative performance of two or more filters operating under similar but not necessarily identical conditions. Factors affecting the F.P.I. are the quantity of turbidity removed, the volume of water produced during a filter run, and the effluent quality. The higher the F.P.I. the better the performance of the filter. Mathematically the F.P.I. is represented as:

$$\text{F.P.I.} = \frac{(\text{NTU}_a - \text{NTU}_e)G}{\text{NTU}_e}$$

where

NTU_a = turbidity in units applied to the filter
NTU_e = turbidity in units in filter effluent
G = gallons filtered between backwashes

As seen from Table 8 the highest F.P.I.s were achieved when alum was used as the primary coagulant and the polymer (T-Chem 512) was used as a coagulant aid. During testing period 1 coagulants were not added, resulting in only a small reduction in turbidity. This indicates that very little filtration was taking place through the filter media and further supports Trussell et al. (1980) findings for the need of coagulation chemicals to induce a floc which can be removed by the filter media. The testing periods which used

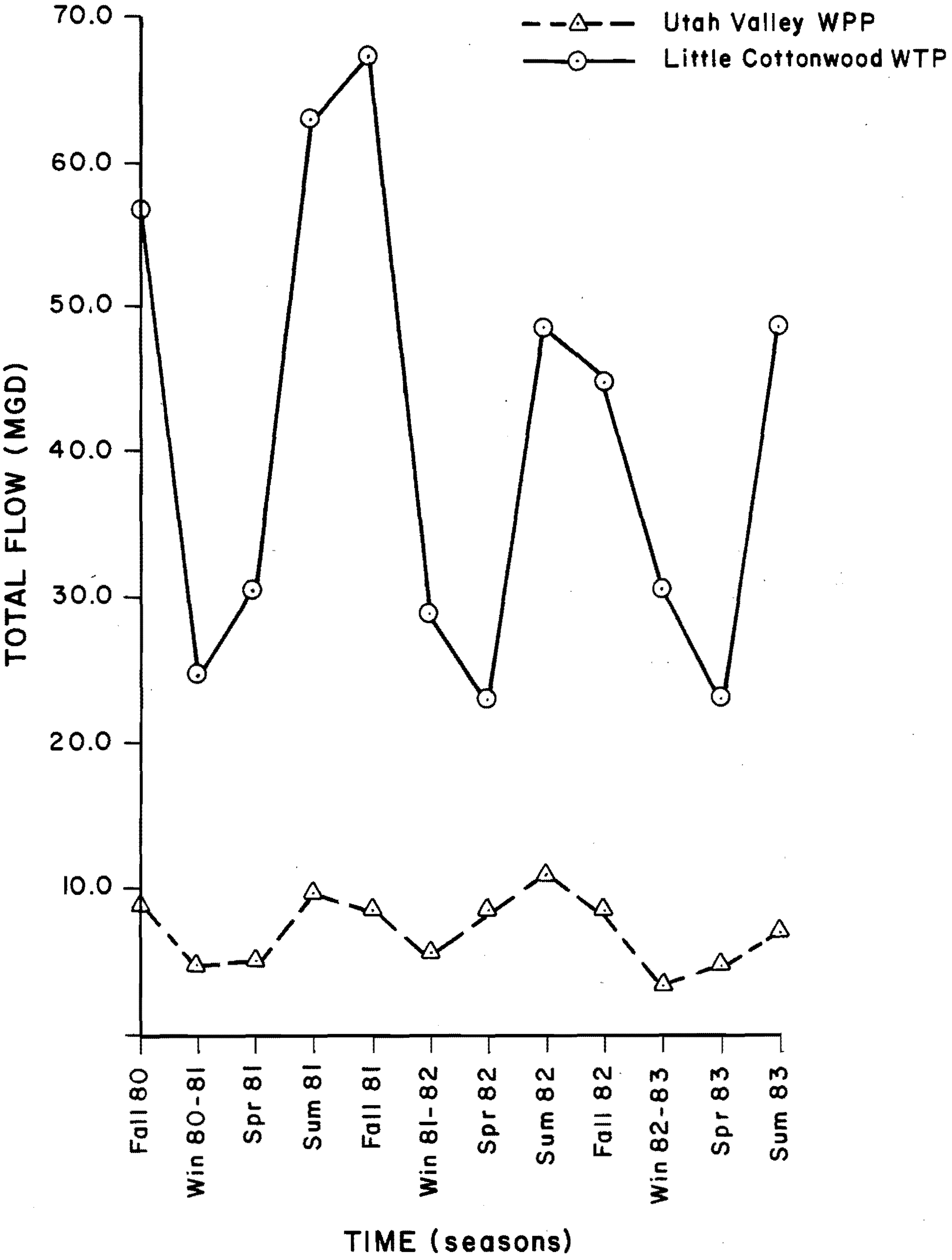


Figure 13. Total flow for the Utah Valley and the Little Cottonwood water treatment plants from August 80 through July 83.

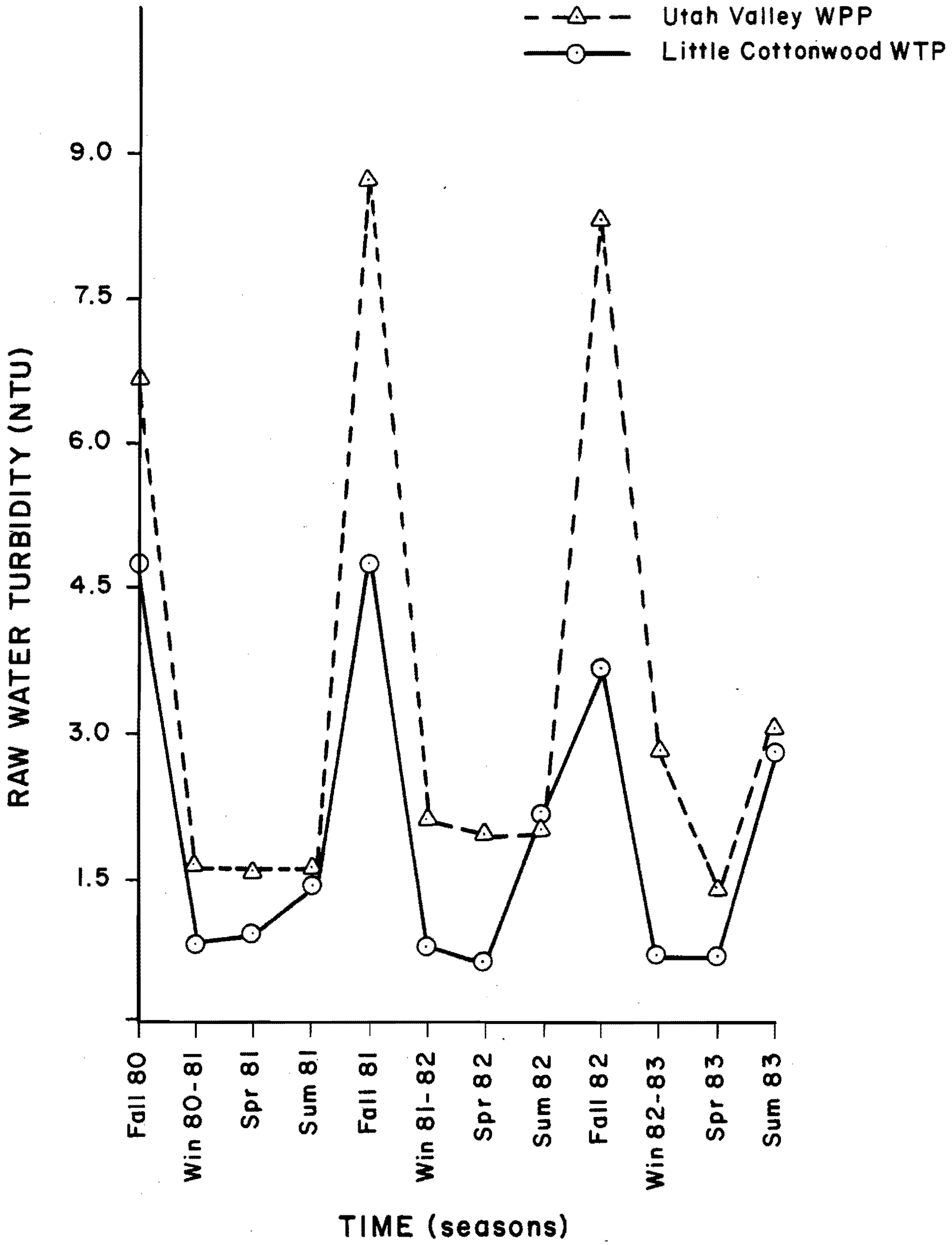


Figure 14. Raw water turbidity for the Utah Valley and the Little Cottonwood water treatment plants from August 80 through July 83.

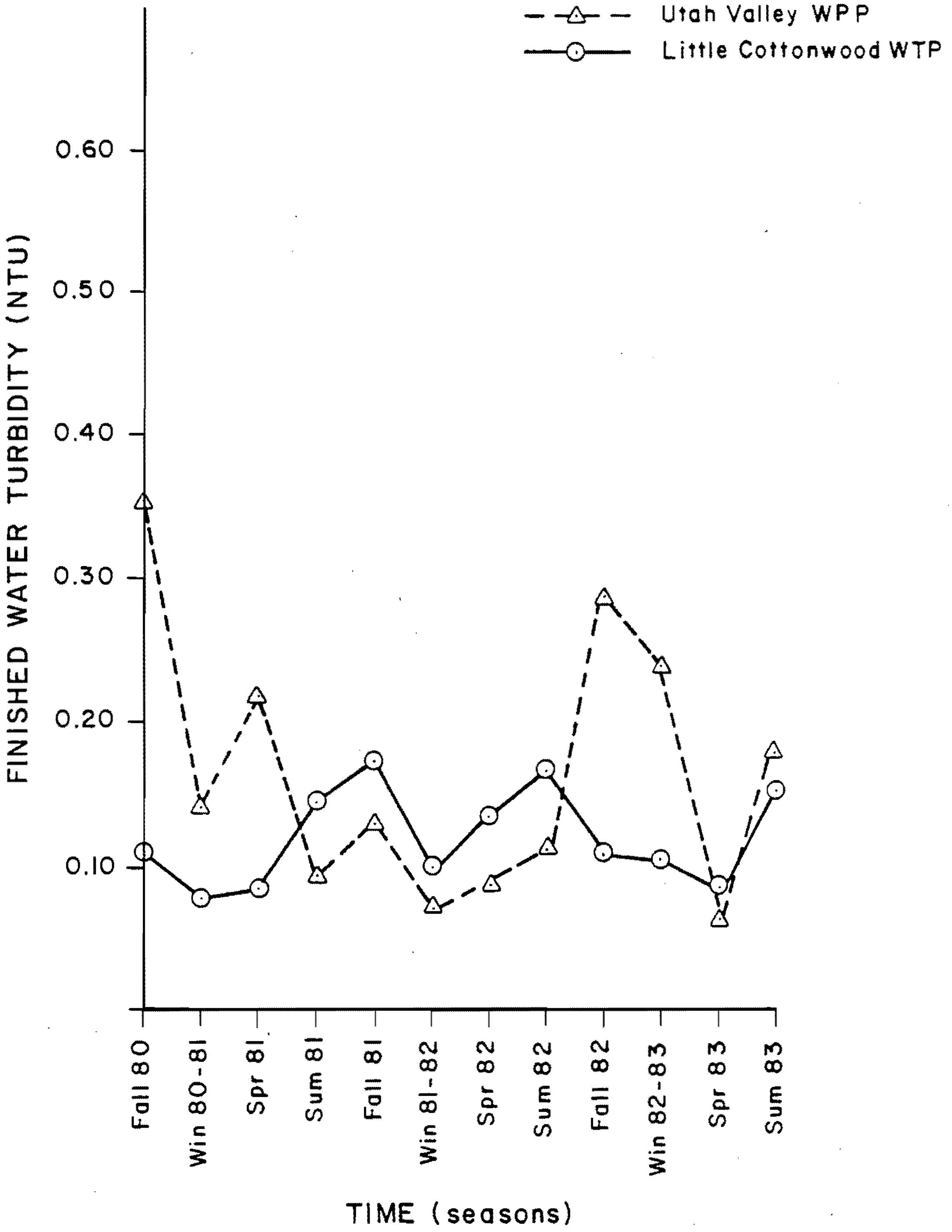


Figure 15. Finished water turbidity for the Utah Valley and the Little Cottonwood water treatment plants from August 80 through July 83.

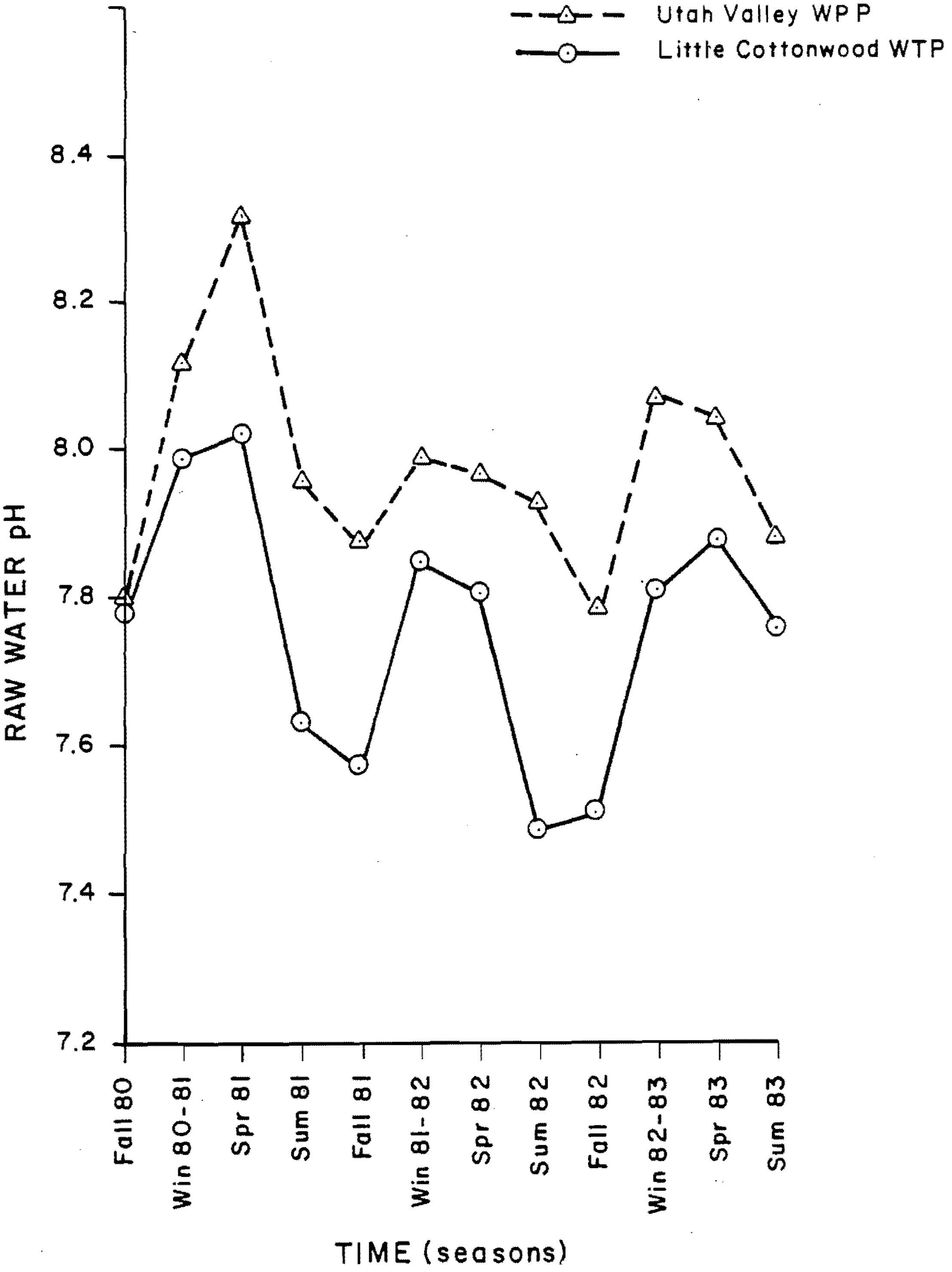


Figure 16. Raw water pH for the Utah Valley and the Little Cottonwood water treatment plants from August 80 through July 83.

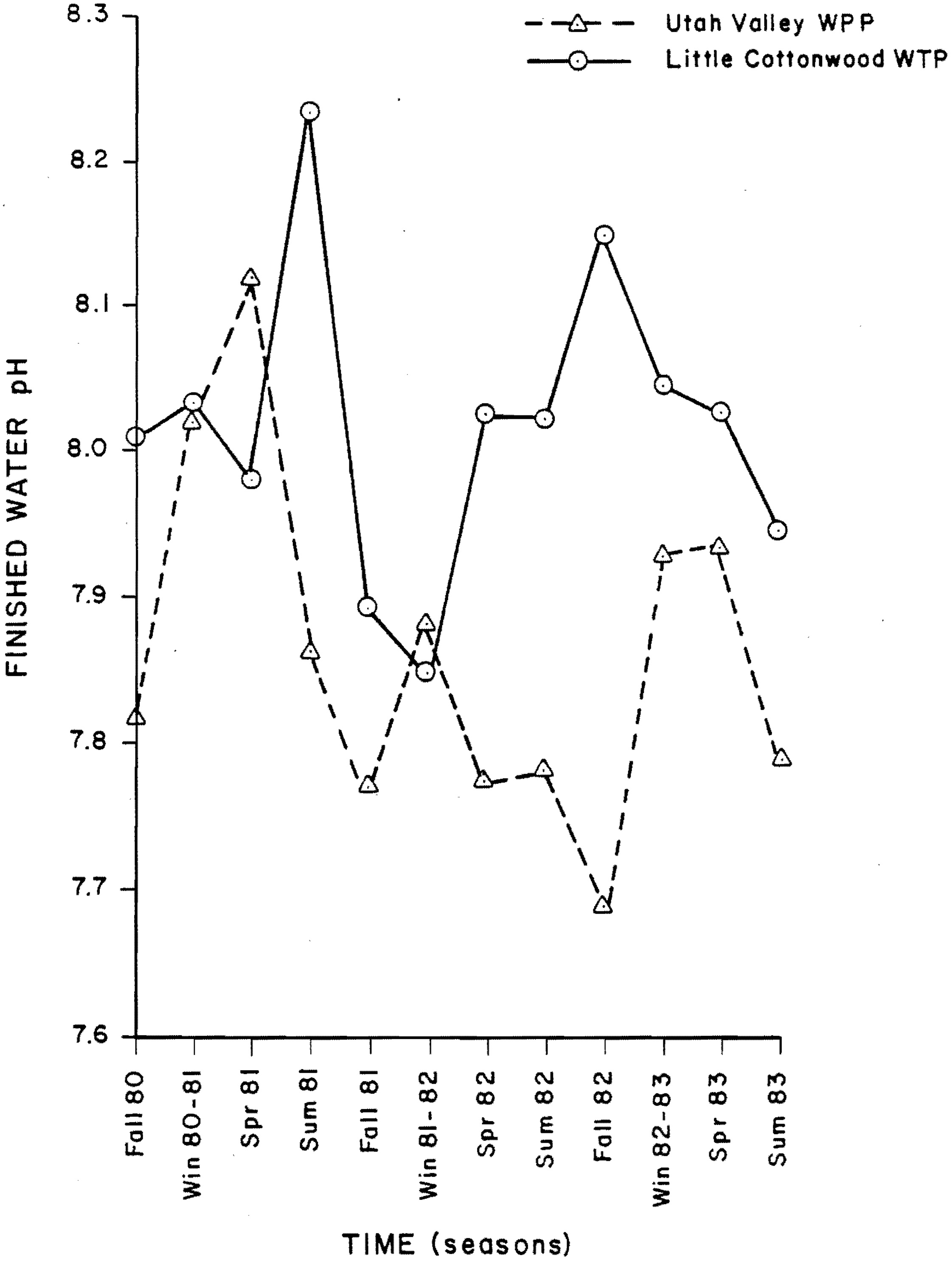


Figure 17. Finished water pH for the Utah Valley and the Little Cottonwood water treatment plants from August 80 through July 83.

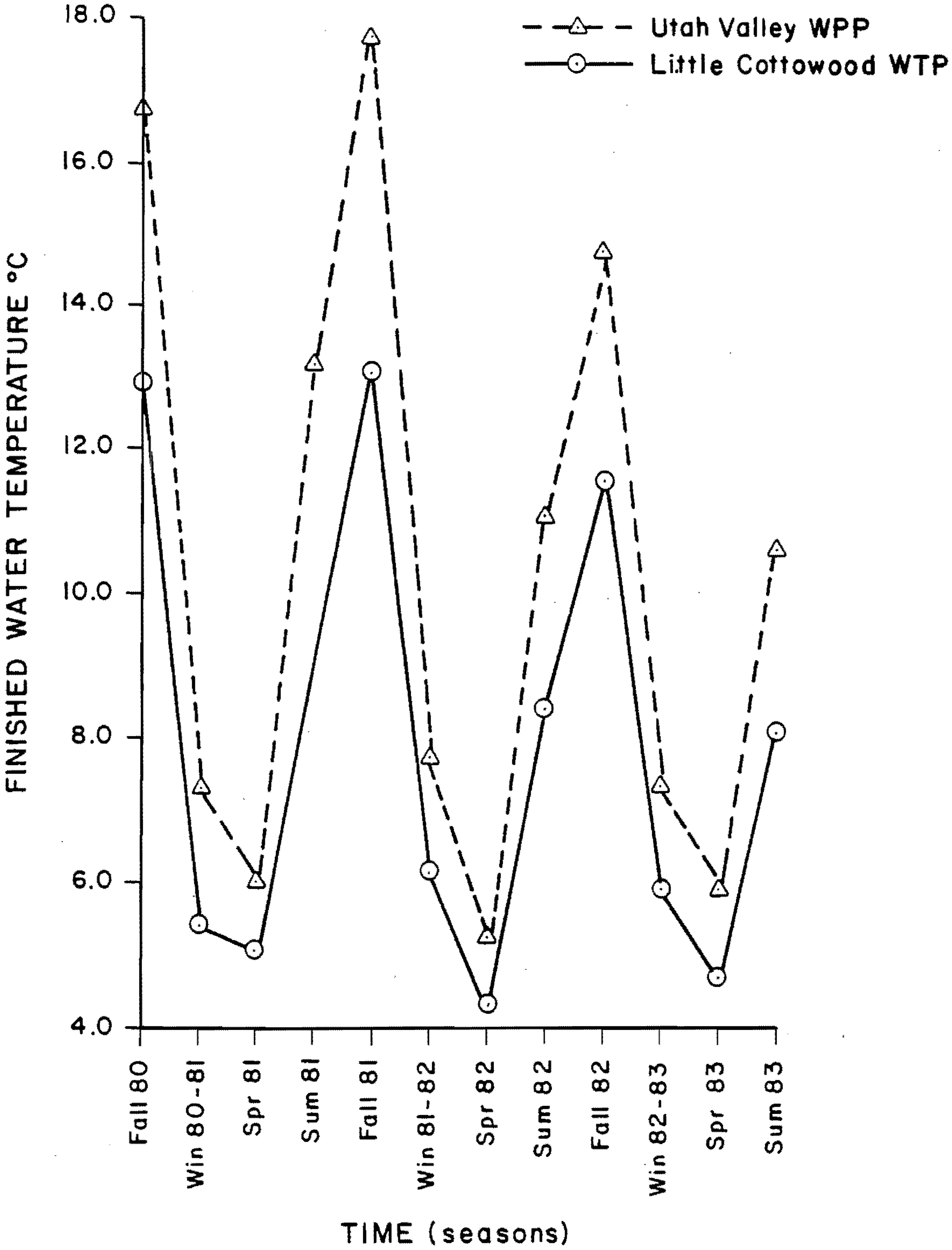


Figure 18. Finished water temperature for the Utah Valley and the Little Cottonwood water treatment plants from August 80 through July 83.

Table 8. Summary of pilot plant performance.

Testing Period and Filter Column	Flow Rate gpm/ft^2	Ave. Turb. (NTU)		Coagulants Added (mg/l)		F.P.I.*
		Raw	Effluent	Alum	Polymer	
1-A	5	3.6	2.9	-	-	43
1-B	5	3.6	2.8	-	-	51
2-A	5	2.7	1.8	-	-	74
2-B	5	2.7	0.87	-	-	311
3-A	5	8.1	4.1	6.8	-	260
3-B	5	8.1	3.8	6.8	-	301
4-A	5	8.3	4.3	15.0	-	137
4-B	5	8.3	2.7	15.0	-	306
6-A	5	10.3	1.9	15.0	-	769
6-B	5	10.3	2.3	15.0	-	627
7-A	5	11.3	3.1	10.0	-	387
7-B	5	11.3	1.1	20.0	-	1,107
8-A	5	21.4	0.15	6.7	0.67	16,745
8-B	5	21.4	2.4	9.4	0.81	1,677
9-A	5	23.8	2.5	8.9	0.99	998
9-B	5	23.8	2.6	3.4	0.28	956
10-A	5	22.8	1.9	7.5	0.53	1,663
10-B	5	22.8	0.99	8.1	0.70	3,256
11-A	5	15.5	0.29	7.1	1.20	7,867
11-B	4	15.5	0.21	7.6	1.30	12,049
12-A	4	13.6	0.24	3.3	1.30	10,528
12-B	4	13.6	0.16	8.3	1.50	17,872
13-A	3	18.3	0.28	3.3	1.30	10,270
13-B	4	18.3	0.27	4.4	2.20	17,365
14-A	3	14.9	0.23	3.9	1.40	11,270
14-B	4	14.9	0.23	2.1	1.50	10,519

*F.P.I. = Filter Performance Index

alum as the only coagulant at a loading rate of 5 gpm/ft^2 did not produce an average effluent turbidity below the EPA Primary Drinking Water Regulation of a maximum contaminant level of 1 NTU. Test period 7-B had an alum dose of 20.0 mg/l and produced the lowest finished water turbidity of 1.1 NTU for a testing period with alum as the sole coagulant. However this higher alum dose was coupled with a faster increase in headloss across the filter. The filter run time was only 4 hours before terminal headloss (8 feet) was reached. The maximum filter run time at 5 gpm/ft^2 for an alum dose greater than 10 mg/l was 6 hours before terminal headloss was reached with the finished water turbidity never below 1.1 NTU.

The highest F.P.I. (from Table 8) was achieved at a filter loading rate of 4 gpm/ft^2 with an alum dose of 8.3 mg/l and a polymer dose of 1.5 mg/l. The filter run time for these parameters was 9 hours before terminal headloss was reached. This testing period also produced the lowest average finished water turbidity (0.16 NTU) for the course of the pilot plant study.

Testing period 13-B exhibited the second highest F.P.I. of 17,365 which was only slightly lower than the highest F.P.I. of 17,872. This filter run was characterized by a loading rate of 4 gpm/ft2, an alum dose of 4.4 mg/l, a polymer dose of 2.20 mg/l, and a filter run time of 11 hours. Comparing this filter run with that producing the highest F.P.I. (test period 12-B) it is seen that by decreasing the alum dose 50 percent and increasing the polymer dose 32 percent a high quality effluent could still be achieved with a longer filter run time. Note also that filter run 13-B was treating a raw water of 4.7 turbidity units higher than that of the superior filter run. Filter run 14-B was a further decrease in the alum dose of 75 percent from that of test period 12-B. The polymer doses for both runs was 1.50 mg/l. Although the F.P.I. for 14-B was less than that of 12-B an acceptable effluent of 0.23 NTU was produced.

A cost analysis for the alum and polymer doses of filter runs 12-B, 13-B, and 14-B was completed for the Utah Valley Water Purification Plant. These testing periods were chosen because they were all conducted at 4 gpm/ft^2 and they produced a finished water turbidity well below the EPA's maximum contaminant level of 1 TU. In the analysis it was assumed that a combination of alum and polymer would be used from August 1 through October 31 which generally corresponds to the period of the highest turbidity. The volume of water treated at the Utah Valley plant in 1984 for this period was 1,073 million gallons. The 1984 Utah Valley cost for alum was \$.09/lb and \$.82/lb for the T-Chem 512 polymer. The results for the cost analysis of the three different coagulant dosing combinations are presented in Table 9. Note, the cost analysis is based only on the cost of the chemicals and does not include the operation and maintenance of the chemical feed equipment.

As shown in Table 9 the optimum coagulant dose for the best filter performance is not necessarily the most economical. Although filter run 14-B has a lower F.P.I. than the other two filter runs it provides at least a 39 percent savings in chemical costs and still produces an EPA acceptable quality of water.

As shown in Table 8 decreasing the filter loading rate from 4 gpm/ft2 did not increase the F.P.I. Filter runs 12-A and 13-A were conducted at 4 gpm/ft2 and 3 gpm/ft2, respectively. The alum and polymer doses for these testing periods were equal as was the filter run time of 9 hours. The F.P.I. for the two testing periods differed by only 258 with testing period 12-A (4 gpm/ft2) exhibiting the higher F.P.I. These results substantiate the Committee's (1980) findings that the crucial parameter in controlling filter run times is not the filtration rate, but rather proper coagulant dosage. As the data log sheets from Appendix C indicate, the average raw water temperature ranged from 13.4 to 14.8°C, whereas the average effluent temperature for both filters was between 16.6 and 17.9°C. The minimum change in average temperature between influent and effluent was during test period 8 with an increase in temperature of 2.5°C at the effluent. The maximum change in average temperature occurred during test period 11 with an increase of 3.5°C from the influent to the effluent. The increase in the temperature is a result of the raw water starting to equilibrate with the average ambient temperature of 20°C as it passed through the filter system. The increase in temperature over time resulted in a decrease of dissolved oxygen. As this occurred air was entrapped between filter media particles, consequently increasing the headloss across the filter. This accounts for the initial headloss across the filters being greater than the calculated 33.5 inches of media headloss. The finished water temperatures of the pilot plant correspond to the mean fall finished water temperatures found in Table 17 (Appendix

Table 9. Cost analysis for different coagulant dosing combinations.

Testing Period	Coagulant dose (mg/l)		Coagulant Cost ($)		Total Cost ($)	F.P.I.
	Alum	Polymer	Alum	Polymer		
12-B	8.3	1.50	6,691	11,016	17,707	17,872
13-B	4.4	2.20	3,547	16,158	19,705	17,365
14-B	2.1	1.50	1,693	11,016	12,709	10,519

B) for the Utah Valley treatment plant. Generally, the average water temperature for the Utah Valley plant ranges between 15.0 to 17.6°C during the months of the pilot plant study.

The average raw water pH ranged from 7.2 to 7.8 and the finished water pH between 7.6 to 8.2. The maximum change for any test period in pH was only an increase in 0.5 units from influent to effluent. As seen in Table 17 (Appendix B) the mean seasonal finished water pH is between 7.8 to 8.1 which is within 0.2 units of the pilot plants. This indicates that the pilot plant pH does not need to be adjusted. In addition the pilot plant finished water pH falls within the range of desirable finished water pH of 7.8 ± 0.4.

CONCLUSIONS

Overall the data exhibit that the direct filtration process employed at the Utah Valley Water Purification Plant produces an acceptable quality of water and one that is comparable in quality to that produced by the conventional process at the Little Cottonwood Water Treatment Plant.

The pilot scale direct filtration system was unable to treat a raw water with a turbidity of 8.1 NTU or greater using alum as the sole coagulant. Alum doses of up to 20 mg/l were added to the system, but the raw water turbidity was only reduced to 1.1 NTU, not meeting EPA regulations. A combination of alum and polymer was necessary during the testing period of the pilot plants to meet the EPA regulations.

In general the pilot scale direct filtration system produced acceptable finished water when alum was used as the primary coagulant with a polymer as a coagulant aid. Several testing periods characterized by different raw water turbidities, filter loading rates, and coagulant doses were able to meet the EPA Primary Drinking Water Regulation of 1 NTU maximum contaminant level.

The optimum filter run based on filter performance, for the pilot scale direct filtration system was achieved with a filter loading rate of 4 gpm/ft^2, an alum dose of 8.3 mg/l, and a polymer (T-Chem 512) dose of 1.50 mg/l. The average raw water turbidity during this testing period was 13.6 NTU with an average finished water turbidity of 0.16 NTU.

The most economical coagulant dose for the Utah Valley Water Purification Plant for the months of August, September, and October was 2.1 mg/l alum and 1.50 mg/l polymer (T-Chem 512). This is based on the 1984 costs for the coagulant chemicals and includes only the costs of the chemicals. At this chemical dosing and a filter loading rate of 4 gpm/ft^2 a finished water turbidity of 0.23 NTU was achieved.

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APPENDICES

Appendix A

Sample Data Log Sheets From The Utah Valley Water Purification Plant and the Little Cottonwood Water Treatment Plant

Table 10. Utah Valley Water Purification Plant data for the month of August, 1981.

FILTER OPERATION								CHEMICALS USED					
Date	Weather	Total Amount Water Used	Flow Rate M2 / sec.	Filter Rate m/Day	Length of Filter Run	Filter Head Loss	Minutes of Backwash	Alum Mg/1	KMNO4 Mg/1	Carbon Mg/1	PEC Mg/1	Chlorinator Setting	Cylinder Weight
1	Clear	33745	.39	124	-	-		8					
2	Clear	33825	.39	125				8	.60				
3	Clear	34675	.40	128	-	-		8	.60				
4	Clear	34830	.40	128				8	.60				
5	Clear	39040	.45	115	-	-							
6	Clear	39258	.45	115									
7	Clear	39771	.46	117				8	.60				
8	Clear	45434	.53	132				8	.60				
9	Clear	43065	.50	127				8	.6				
10	Cloudy	41269	.48	122				13	.6				
11	Cloudy	39818	.46	117				13	.6				
12	Cloudy	37920	.44	112				13	.6				
13	Cloudy	40354	.47	118				13.6	.6				
14	Cloudy	43704	.51	127	24	.8		8	.6				
15	Pt. Cdy	38649	.45	113				10.8	.6				
16	Clear	40607	.47	118	26	.8		8.14	.6				
17	Clear	43876	.49	127	*	*		8.0	.6				
18	Clear	34200	.39	100	36	.5		8.0	.8				
19	Clear	27103	.31	80				8	.8				
20	Clear	23621	.27	70				8/15	1/1.2				
21	Rain	25927	.30	76	61.5	.5		15	2.2				
22	Clear	29699	.34	87				15	2.2				
23	Rain	28475	.33	83				15	2.2				
24	Clear	23714	.27	69				15	2.2				
25	Clear	30375	.35	.89				10	2.2				
26	Clear	31380	.36	93				15	1.4				
27	Clear	32424	.37	95				10	1.5				
28	Rain	34306	.40	101				10	1.5				
29	P.C.	33495	.39	98				10	1.5				
30	P.C.	30378	.35	89				10	1.5				
31	Clear	36720	.42	108	**	**		10	1.5				
Total		1090857		3303				317.54					
Ave.		35188	.41	106	40	.43		10.58	1.12				
Max.		45434	.51	132	147	1.2		15	2.2				
Min.		23621	.27	70	20	0		8	.60				

Table 10. Continued.

CHEMICAL OR PHYSICAL TESTS																
Chlorine Residual		Turbidity			Water Temperature	pH			Odor		Color		Hardness	
A.M.	P.M.	Raw	App.	Fin.		Raw	App.	Fin.	Raw	Fin.	Raw	Fin.	Raw	Fin.
.61	.60	5.9		.11	18.1									
.62	.60			.16										
.59	.55	8.7	.36	.31	18.2	8.0		8.0			20	5	178	177
.51	.53	6.9		.52	19.6	8.0		8.0			20	5	172	174
.65	.50	8.6		.17	18.5	7.9		7.9			25	5	176	175
.60	.42	9.0		.16	19.2	7.9		7.9	4	2	40	5	176	174
.55	.48	7.1	.50	.20	18.7	7.9		7.9					174	175
.53	.44	7.3		.17	19.3	7.9		7.9						
.58	.55					7.9		7.9						
.65	.65	5.3		.28	19.5	7.9		7.9			20	5	175	174
.65	.60	4.9	.18	.19	19.2	7.8		7.8			13	5	174	174
.70	.65	5.9		.18	19.1	7.9		7.9			20	3	176	175
.75	.68	4.9		.09	18.0	7.9		7.8			20	3	181	168
.57	.57	4.6		.19	18.0	7.9		7.9	4	1.4	15	3	173	168
.60	.57	5.7		.24	18.3									
.60	.55	6.1		.08	17.7									
.52	.55	6.8		.22	17.9	7.9		7.8			20	3	172	170
.55		10.1	.36	.08	18.5	7.9		7.8			50	4	171	169
.65	.50	11.0	1.8	.35	19.3	7.9		7.8			60	5	171	168
.55	.55	10.2		.15	19.2	7.9		7.8	4	2	50	4		
.50		14.1		.06	19.8	7.9		7.8			60	3		
.65	.58	12.4		.08	20	7.8		7.8					171	164
.74	.78	11.1		.05										
.68	.68	15.1		.18	19.1	7.8		7.7			60	4		
.72	.70	15.7		.19	18.8	7.8		7.6			60	3	170	167
.55	.48	11.1		.06	19.7	7.9		7.7			60	3	173	170
.65	.53	12.5		.09	20	7.8		7.7	6	3			174	173
.62	.68	10.3		.10	20.3	7.8		7.7			60	4	170	167
.42	.70	10.9		.06	20									
.63	.51	11.1		.13										
.35		14.3		.11	19.9	7.8	7.2	7.7			50	4	172	170
.60	.58	9.4	.14	.17	18.4	7.8			4.5	2.1	38	4	173	171
.75	.78	16.1	1.8	.52	20.3	8.0			6	3	60	5	181	175
.35	.42	4.6	.18	.05	17.7	7.8			4	1.4	13	3	170	167

Table 10. Continued.

Alkalinity				End 2015752 Beg 1933114 82638		
Conduct		Alkai				
Row	Fin.	Row	Fin.	Temp.		
				High	Low	
				95	70	
				97	74	
357	350	129	128	97	71	
		132	125	96	72	
		129	123			
		127	123			
369	365	131	122			
				93	72	
				90	65	
		130	122		66	
		131	121		57	
		128	122	79	62	
		128	123	79	60	
360	350	129	125	85	58	
				88	63	
				87	61	
		126	125	90	64	
		128	126			
356	337	128	132	90	63	
				91	68	
				97	64	
		126	121	88	63	
				87	67	
355	343	126	125	90	58	
		130	120	93	71	
		128	119	90	68	
		130	121	90	64	
350	340	132	122			
				89	63	
		129	121			
357	347	129	123	90	65	
369	365	131	128	97	74	
350	337	127	119	79	57	

Table 11. Little Cottonwood Water Treatment Plant data for the month of July, 1983.

DATE	TOTAL ALKALINITY as $CaCO_3$			pH UNITS			TOTAL HARDNESS as $CaCO_3$			COLOR Pt-Co Units		
	LITTLE COTTONWOOD	DEER CREEK	FINISHED	LITTLE COTTONWOOD	DEER CREEK	FINISHED	LITTLE COTTONWOOD	DEER CREEK	FINISHED	LITTLE COTTONWOOD	DEER CREEK	FINISHED
1		141	140		7.75	7.70		149	170		25	< 1
2		138	134		7.75	7.75		151	160		25	< 1
3												
4												
5		140	138		7.66	7.63		148	149		30	< 1
6	38	152	109	7.78	7.66	7.79	45	157	137	20	30	< 1
7	40	131	132	7.71	7.74	7.80	43	141	156	20	25	< 1
8	32	132	113	7.69	7.71	7.83	52	145	158	20	20	< 1
9		133	117		7.79	8.02		146	153		20	< 1
10												
11		142	126		7.67	7.80		138	144		25	< 1
12	37	128	121	7.60	7.69	7.97	53	162	148	20	25	< 1
13	37	129	104	7.74	7.69	8.12	45	176	135	15	25	< 1
14	35	129	87	7.82	7.75	8.22	65	152	132	15	25	< 1
15	43	129	82	7.83	7.70	8.15	54	153	107	25	25	< 1
16												
17												
18		116	126		7.60	7.88		122	136		25	< 1
19	44	125	86	7.83	7.70	8.28	38	126	96	17	25	< 1
20	36	120	102	7.91	7.66	7.93	35	120	117			
21	36	121	90	7.89	7.74	8.15	40	119	100			
22	35	123	103	7.82	7.76	8.29	43	122	132	15	27	< 1
23												
24												
25												
26		153	137		7.55	7.93		144	151		30	< 1
27		116	125		7.55	7.89		135	151		35	< 1
28	37	120	86	7.82	7.62	8.04	40	107	96			
29	39	121	78	7.90	7.69	8.01	43	126	98			
30												
31												
TOTAL	489	2739	2336	101.3	161.4	167.2	596	2813	2826	167	442	< 1
AVE.	38	130	111	7.80	7.69	7.96	33	134	134	19	26	< 1
MAX.	44	153	140	7.91	7.79	8.29	65	176	170	20	30	< 1
MIN.	32	116	78	7.60	7.60	7.63	35	107	96	15	20	< 1

Table 11. Continued.

DATE	TURBIDITY N.T.U.			ODOR T.O. No.							
	LITTLE COTTONWOOD	DEER CREEK	FINISHED	DEER CREEK	LITTLE COTTONWOOD	MIXED RAW	FINISHED	94th SOUTH			
1		3.50	0.17	6			N.O.O	N.O.O.			
2		3.80	0.09								
3			0.08								
4			0.10								
5		4.20	0.19								
6	4.70	3.90	0.47								
7	5.90	3.50	0.20								
8	7.00	4.00	0.15	6	1		N.O.O	N.O.O.			
9		3.90	0.17								
10			0.17								
11		3.70	0.10								
12	9.40	3.90	0.13								
13	3.60	3.90	0.25								
14	3.40	3.90	0.53	6	1		N.O.O	N.O.O.			
15	5.90	4.10	0.30								
16			0.13								
17			0.22								
18		4.40	0.34								
19	2.00	4.40	0.39								
20	1.90	5.60	0.22								
21	2.50	4.60	0.27								
22	1.90	4.40	0.17								
23			0.14								
24			0.11								
25			0.19								
26		4.90	0.15								
27		5.10	0.31	6	1		N.O.O	N.O.O.			
28	2.20	4.40	0.21								
29	1.70	9.60	0.14								
30			0.15								
31			0.16								
TOTAL	52.1	93.7	6.40	24	3		N.O.O	N.O.O.			
AVE.	3.47	4.46	0.20	6	1		N.O.O	N.O.O.			
MAX.	9.40	9.60	0.53	6	1		N.O.O	N.O.O.			
MIN.	1.70	3.50	0.08	6	1		N.O.O	N.O.O.			

Table 11. Continued.

DATE	APPLIED WATER DATA (at filters)		FINISHED WATER AVERAGE CHLORINE RESIDUAL	CHLORINE RESIDUAL TERMINAL RESERVOIR		RAW WATER FLOW M.G.D.		WATER TEMP. °F	
	TURBIDITY	pH		INFLUENT	EFFLUENT	LITTLE COTTONWOOD	DEER CREEK	MIXED	FINISHED
1	0.82	7.79	1.03	1.34	0.57		70	44	49
2	1.40	7.69	1.12				52	44	49
3			1.08				52	44	49
4			1.07				52	44	49
5	0.82	7.70	1.01	1.46	0.59	19	71	44	49
6	1.20	7.83	1.04	1.12	0.59	35	85	44	49
7	2.10	7.92	1.24	1.32	0.77	26	67	44	49
8	1.30	7.98	1.19	1.25	0.75	33	60	44	49
9	3.10	7.93	1.05			12	65	44	49
10			1.08				36	44	49
11	0.41	8.06	1.02	1.20	0.72		56	44	49
12	0.64	8.10	1.00	1.18	0.54	48	38	44	49
13	1.10	8.15	1.07	1.10	0.69	21	48	44	49
14	1.10	8.34	1.09	1.80	1.00	45	48	44	47
15	1.40	8.18	1.04	1.42	0.72	19	50	44	47
16			1.02				45	44	47
17			1.03				61	44	47
18	2.80	7.95	1.06	1.18	1.00	19	77	44	50
19	1.70	8.50	1.09	1.43	0.93	39	62	44	48
20	3.70	8.32	1.11	0.98	1.15	10	97	44	50
21	2.90	8.46	1.07	1.70	1.15	59	56	44	48
22	2.20	8.49	1.06	1.90	1.05	19	52	44	49
23			0.97			19	52	44	49
24			1.08			19	52	44	50
25			1.06			19	52	45	51
26	0.92	8.19	1.09	1.42	0.75		70	45	51
27	1.90	8.07	1.04	1.05	0.65	52	64	44	51
28	1.50	8.33	1.12	1.45	0.72	54	36	44	49
29	1.30	7.97	1.14			35	38	44	49
30			1.12			35	38	44	49
31			1.06			35	38	44	49
TOTAL	34.3	169.9	33.3	24.3	14.3	672	1702	1366	1518
AVE.	1.63	8.09	1.07	1.35	0.79	30	54	44	48
MAX.	3.70	8.50	1.24	1.90	1.15	48	97	45	51
MIN.	1.10	7.95	0.97	0.98	0.54	12	36	44	47

Table 11. Continued.

DATE	TREATMENT MILLIGRAM PER LITER (PPM)																	
	AERATION	LIME	ALUM			K Mn O_4			COAGULANT AID						CARBON			
									SILICA									
		PRE-MIXERS	PRE-AERATION	PRE-MIXERS	FLASH MIXERS	PRE-AERATION	PRE-MIXERS	FLASH MIXERS	PRE-AERATION	PRE-MIXERS	FLASH MIXERS	PRE-AERATION	PRE-MIXERS	FLASH MIXERS	PRE-AERATION	PRE-MIXERS	FILTERS	
1		6		25		.27			2									
2		6		25		.27			2									
3		7		25		.30			2									
4		7		25		.30			2									
5		5		25		.30			2									
6		10		30		.25			2									
7		10		30		.25			2									
8		10		30		.27			2									
9		12		30		.27			2									
10		10		25		.29			2									
11		10		25		.29			2									
12		12		30		.29			2									
13		11		25		.20			2									
14		12		30		.20			2									
15		12		30		.20			2									
16		12		30		.20			2									
17		12		30		.20			2									
18		10		25		.25			2									
19		11		25		.25			2									
20		12		25		.25			2									
21		13		30		.25			2									
22		14		30		.25			2									
23		14		30		.28			2									
24		14		30		.28			2									
25		12		25		.28			2									
26		12		25		.28			2									
27		11		30		.28			2									
28		11		30		.28			2									
29		11		30		.20			2									
30		12		30		.20			2									
31		12		30		.20			2									
TOTAL		333		865		7.88			62									
AVE.		10		27		.25			2									
MAX.		14		30		.30			2									
MIN.		10		25		.20			2									

Appendix B

Statistical Data for Random Block Design Analysis of Variance

Table 12. Statistical data for analysis of variance for total flow (MGD).

	Utah Valley Water Purification Plant			Little Cottonwood Water Treatment Plant		
	Mean Y_i	Std. Deviation S_i	Sample Size n_i	Mean Y_i	Std. Deviation S_i	Sample Size n_i
Fall 80	8.788	2.721	92	56.691	24.689	68
Winter 80-81	4.864	0.459	31	24.557	6.857	79
Spring 81	5.462	1.190	83	30.372	10.282	78
Summer 81	9.576	2.701	92	62.906	34.415	85
Fall 81	8.213	1.958	92	67.333	33.860	87
Winter 81-82	5.819	0.804	92	28.837	6.960	92
Spring 82	8.416	1.738	89	22.977	10.107	88
Summer 82	10.703	1.818	92	48.438	24.521	89
Fall 82	8.133	3.675	78	44.467	24.268	90
Winter 82-83	3.337	0.810	92	30.363	7.574	91
Spring 83	4.481	0.888	88	22.977	10.107	88
Summer 83	6.770	1.384	92	48.438	24.521	89

Table 13. Statistical data for analysis of variance for raw water turbidity (NTU).

	Utah Valley Water Purification Plant			Little Cottonwood Water Treatment Plant		
	Mean Y_i	Std. Deviation S_i	Sample Size n_i	Mean Y_i	Std. Deviation S_i	Sample Size n_i
Fall 80	6.6598	4.4135	87	4.7803	4.0606	60
Winter 80-81	1.6897	0.6977	87	0.8532	0.4243	75
Spring 81	1.5972	0.4249	71	0.9251	0.3590	73
Summer 81	1.6400	1.4564	85	1.4881	1.0847	68
Fall 81	8.7141	4.6027	85	4.7849	2.7017	67
Winter 81-82	2.1598	0.9790	92	0.8187	0.3185	63
Spring 82	1.9931	1.1625	87	0.6046	0.2671	65
Summer 82	2.0176	0.6164	91	2.1842	0.9444	43
Fall 82	8.2769	5.1244	78	3.6636	2.2407	58
Winter 82-83	2.8363	1.7993	91	0.6947	0.5211	38
Spring 83	1.4414	0.9191	87	0.6710	0.3346	58
Summer 83	3.0934	1.0249	91	2.8588	2.1624	26
August 83	5.8379	2.1563	29	3.8718	1.7955	11

Table 14. Statistical data for analysis of variance for finished water turbidity (NTU).

	Utah Valley Water Purification Plant			Little Cottonwood Water Treatment Plant		
	Mean Y_i	Std. Deviation S_i	Sample Size n_i	Mean Y_i	Std. Deviation S_i	Sample Size n_i
Fall 80	0.35593	0.36278	86	0.10835	0.04339	85
Winter 80-81	0.14077	0.5157	86	0.07711	0.01550	83
Spring 81	0.21833	0.9798	72	0.0854	0.03934	89
Summer 81	0.09488	0.06079	86	0.14304	0.09870	92
Fall 81	0.12919	0.07892	86	0.17326	0.08891	92
Winter 81-82	0.07109	0.03011	92	0.09811	0.04058	90
Spring 82	0.08545	0.02904	88	0.13693	0.05004	88
Summer 82	0.11374	0.03687	91	0.16589	0.03342	90
Fall 82	0.28756	0.21074	78	0.10700	0.02939	90
Winter 82-83	0.23912	1.46788	91	0.10176	0.03690	91
Spring 83	0.06118	0.02422	85	0.08148	0.01466	88
Summer 83	0.17910	0.12955	89	0.15222	0.11206	90
August 83	0.60000	0.27905	88	0.14767	0.07113	30

Table 15. Statistical data for analysis of variance for raw water pH.

	Utah Valley Water Purification Plant			Little Cottonwood Water Treatment Plant		
	Mean Y_i	Std. Deviation S_i	Sample Size n_i	Mean Y_i	Std. Deviation S_i	Sample Size n_i
Fall 80	7.7793	0.1490	73	7.7538	0.1356	60
Winter 80-81	8.1224	0.1062	85	7.9892	0.0542	76
Spring 81	8.3174	0.1248	69	8.0293	0.0957	75
Summer 81	7.9639	0.1274	83	7.6391	0.1963	67
Fall 81	7.8788	0.0827	71	7.5693	0.2076	64
Winter 81-82	7.9854	0.0739	82	7.8534	0.0753	62
Spring 82	7.9730	0.1995	74	7.8192	0.0859	66
Summer 82	7.9388	0.1707	69	7.4969	0.1765	42
Fall 82	7.7712	0.1702	59	7.511	0.2347	56
Winter 82-83	8.0734	0.0740	64	7.8279	0.0841	38
Spring 83	8.0576	0.0724	59	7.8811	1.095	57
Summer 83	7.8816	0.1236	49	7.7644	0.0759	27
August 83	7.6400	0.0737	15	7.77550	0.0942	12

Table 16. Statistical data for analysis of variance for finished water pH.

	Utah Valley Water Purification Plant			Little Cottonwood Water Treatment Plant		
	Mean Y_i	Std. Deviation S_i	Sample Size n_i	Mean Y_i	Std. Deviation S_i	Sample Size n_i
Fall 80	7.8238	0.1705	84	8.0097	0.1909	64
Winter 80-81	8.0236	0.1128	89	8.0340	0.1536	75
Spring 81	8.1246	0.0991	69	7.9816	0.1672	76
Summer 81	7.8628	0.0971	86	8.2363	0.3735	76
Fall 81	7.7708	0.1067	72	7.8961	0.1649	75
Winter 81-82	7.8805	0.0761	82	7.8495	0.1775	66
Spring 82	7.7733	0.1613	75	8.0264	0.2320	74
Summer 82	7.7855	0.1342	69	8.0226	0.3375	74
Fall 82	7.6950	0.1500	60	8.1476	0.2461	74
Winter 82-83	7.9354	0.0892	65	8.0429	0.2464	73
Spring 83	7.9533	0.0747	60	8.0284	0.1802	73
Summer 83	7.7902	0.1404	51	7.9442	0.3139	71

Table 17. Statistical data for analysis of variance for temperature (°C).

	Utah Valley Water Purification Plant			Little Cottonwood Water Treatment Plant		
	Mean Y_i	Std. Deviation S_i	Sample Size n_i	Mean i	Std. Deviation S_i	Sample Size n_i
Fall 80	16.798	1.783	87	12.899	1.874	69
Winter 80-81	7.373	2.277	86	5.437	0.892	79
Spring 81	6.017	1.346	71	5.062	0.971	78
Summer 81	13.180	3.577	83	8.831	2.187	86
Fall 81	17.637	2.453	76	13.094	2.661	88
Winter 81-82	7.667	3.005	78	6.183	2.610	92
Spring 82	5.287	1.234	69	4.330	0.620	88
Summer 82	11.091	2.054	76	8.408	1.504	89
Fall 82	14.792	1.215	59	11.599	1.869	90
Winter 82-83	7.353	2.079	74	5.976	2.211	91
Spring 83	5.818	0.716	61	5.696	0.552	88
Summer 83	10.688	1.753	49	8.140	1.810	90

Table 18. Statistical data for analysis of variance for alum (mg/l) dosing.

	Utah Valley Water Purification Plant			Little Cottonwood Water Treatment Plant		
	Mean Y_i	Std. Deviation S_i	Sample Size n_i	Mean Y_i	Std. Deviation S_i	Sample Size n_i
Fall 80	10.663	3.417	92	23.000	7.746	90
Winter 80-81	7.565	0.856	92	16.176	2.795	91
Spring 81	8.012	1.612	83	16.921	7.400	89
Summer 81	11.505	4.009	92	24.315	7.275	92
Fall 81	8.303	9.238	92	29.185	2.701	92
Winter 81-82	11.448	3.677	92	21.522	4.042	92
Spring 82	10.973	2.09	89	17.045	3.985	88
Summer 82	11.612	2.007	92	25.444	1.431	90
Fall 82	13.132	3.002	79	25.278	1.152	90
Winter 82-83	22.223	7.432	92	24.451	1.138	91
Spring 83	17.003	2.796	88	24.034	1.985	88
Summer 83	15.746	3.517	92	25.311	4.239	90

Table 19. Two-way analysis of variance data.

	Degree of Freedom df	Mean Square (MS)						
		Total Flow (MGD)	Raw Turb. (NTU)	Fin. Turb. (NTU)	Raw pH	Fin. pH	Temp. °C	Alum Dose (mg/l)
Location	1	7476.2	15.01	0.0383	0.2388	0.2187	37.777	568.6
Season	12	143.5	8.85	0.0122	0.0480	0.0111	28.646	26.8
Error	12	98.5	1.01	0.0114	0.0103	0.0200	0.803	16.7
Total	25							

Appendix C

Data Log Sheets for the Pilot Scale Direct Filtration System

LOCATION UW/PP - OREM, UTAH

DATE 5 JULY 84

TESTING PERIOD 1

TIME	FILTER OPERATION				PHYSICAL & CHEMICAL CHARACTERISTICS									CHEMICALS ADDED (mg/l)						COMMENTS
	FLOW RATE*		HEADLOSS (in.)		TEMP. °C			pH			TURB. (NTU)			$KMnO_4$		ALUM		POLYMER		* gpm/ft²
(hrs.)	A	B	A	B	RAW	A	B	RAW	A	B	RAW	A	B	A	B	A	B	A	B	
1	5	5	44	40	13	16	16	8.9	8.9	8.9	3.2	2.25	2.4	-0-	-0-	-0-	-0-	-0-	-0-	SYSTEM RUNNING FOR
3	5	5	34	36.5	14	16	16	8.8	8.6	8.55	4.5	2.5	2.5	↓	↓	↓	↓	↓	↓	1/2 hr. PRIOR TO 1st TEST
6	5	5	28.25	28.25	11.5	17	17	8.8	8.4	8.25	3.2	4.0	3.6	↓	↓	↓	↓	↓	↓	
										AVG.	3.6	2.9	2.8							FILTER PUMPS
																				RAN DRY AT ~4.5 hrs

LOCATION UVWPP - OREM, UTAH

DATE 7 JULY 84

TESTING PERIOD 2

TIME	FILTER OPERATION				PHYSICAL & CHEMICAL CHARACTERISTICS									CHEMICALS ADDED (mg/l)						COMMENTS
	FLOW RATE*		HEADLOSS (in.)		TEMP. °C			pH			TURB. (NTU)			$KMnO_4$		ALUM		POLYMER		* gpm/ft²
(hrs.)	A	B	A	B	RAW	A	B	RAW	A	B	RAW	A	B	A	B	A	B	A	B	
1	5	5	20.5	21.0	12.0	21.0	20.5	8.4	8.9	8.65	2.7	1.4	1.0	.60	.60	-0-	-0-	-0-	-0-	
2	5	5	23.0	24.0	11.5	19.0	19.0	8.25	7.9	7.95	2.6	1.6	0.76	.60	.60					VARIABLE FLOW ON SYSTEM A
3	5	5	25.0	26.0	12.5	19.0	19.0	8.65	8.3	8.4	2.8	1.8	0.82	? .60	? .60					
4	5	5	27.5	29.5	13.0	18.0	18.0	8.15	8.65	8.50	2.8	1.9	0.84	? .60	? .60					BY HOUR 4 THE 10 HR SOLN. OF $KMnO_4$ HAD
5	5	5	29.5	32.0	12.0	17.5	18.0	8.5	8.2	8.0	2.6	2.1	0.93	—	—	↓	↓	↓	↓	EMPTIED INTO THE RAW WATER RESERVOIR
										AVG.	2.7	1.8	0.87							EFFLUENT ON A & B WAS DARK PINK
																				$KMnO_4$ OVERDOSE!!

LOCATION UVWPP ~ OREM, UTAH

DATE 16 AUGUST 84

TESTING PERIOD 3

TIME	FILTER OPERATION				PHYSICAL & CHEMICAL CHARACTERISTICS									CHEMICALS ADDED (mg/l)						COMMENTS
	FLOW RATE*		HEADLOSS (in.)		TEMP. °C			pH			TURB. (NTU)			$KMnO_4$		ALUM		POLYMER		* gpm/ft²
(hrs.)	A	B	A	B	RAW	A	B	RAW	A	B	RAW	A	B	A	B	A	B	A	B	
1	5	5	39.5	48.5	14.0	17.0	18.0	7.58	7.6	7.35	7.1	4.8	4.2	.6	.6	6.8	6.8	-0-	-0-	
2	5	5	41.75	54.0	14.0	17.4	17.3	7.89	7.85	7.9	7.2	4.6	4.2	.6	.6	6.8	6.8	↓	↓	
3	5	5	44.0	56.75	14.0	17.3	17.5	7.6	7.97	8.1	8.1	4.4	4.0	.6	.6	6.8	6.8	↓	↓	
4	5	5	47.0	59.5	14.0	17.5	17.6	7.85	8.1	7.99	8.1	4.1	3.8	.6	.6	6.8	6.8	↓	↓	PILOT PLANT SHUT-DOWN, BUT NOT BACKWASHED.
																				ALL LINES WERE CLAMPED AND THE
																				DIFFERENT PROCESSES WERE NOT ALLOWED
																				TO DRAIN. TESTING PERIOD 3
																				WILL BE CONTINUED ON 17 AUGUST 84.

LOCATION UWPP- OREM, UTAH

DATE 17 AUGUST 84

TESTING PERIOD 3 (CONT.)

TIME	FILTER OPERATION				PHYSICAL & CHEMICAL CHARACTERISTICS									CHEMICALS ADDED (mg/l)						COMMENTS
	FLOW RATE*		HEADLOSS (in.)		TEMP. °C			pH			TURB. (NTU)			$KMnO_4$		ALUM		POLYMER		* gpm/ft^2
(hrs.)	A	B	A	B	RAW	A	B	RAW	A	B	RAW	A	B	A	B	A	B	A	B	
5	5	5	48	66.5	16.1	20 C	20.5	7.52	7.85	7.62	7.8	3.4	3.2	.6	.6	6.8	6.8	-0-	-0-	CONTINUATION OF TESTING PERIOD
6	5	5	49	68	15	17.1	17.0	7.65	7.7	7.91	8.5	3.7	3.6	.6	.6	6.8	6.8			FROM 16 AUGUST 84.
7	5	5	55.5	71.5	14.9	17.4	17.8	7.49	7.5	7.68	8.6	3.9	3.7	.6	.6	6.8	6.8			
8	5	5	57.5	73.75	16.5	17.1	17.5	7.49	7.3	7.6	8.9	3.85	3.75	.6	.6	6.8	6.8			
9	5	5	60.5	70	14.9	17.8	17.8	7.39	7.55	7.7	8.5	3.8	3.5	.6	.6	6.8	6.8			PILOT PLANT WAS SHUT-DOWN, BECAUSE
				AVG.	14.8	17.6	17.9	7.61	7.71	7.76	8.1	4.1	3.8							AFTER 9 HRS. NO IMPROVEMENT IN THE
																				EFFLUENT TURBIDITY WAS SEEN.

LOCATION UVWPP - OREM, UTAH

DATE 18 AUGUST 84

TESTING PERIOD 4

TIME	FILTER OPERATION				PHYSICAL & CHEMICAL CHARACTERISTICS									CHEMICALS ADDED (mg/l)						COMMENTS
	FLOW RATE*		HEADLOSS (in.)		TEMP. °C			pH			TURB. (NTU)			KMnO4		ALUM		POLYMER		* gpm/ft²
(hrs.)	A	B	A	B	RAW	A	B	RAW	A	B	RAW	A	B	A	B	A	B	A	B	
1	5	5	63	56	16.0	17.0	17.5	7.32	7.4	7.39	8.3	3.9	.92	.6	.6	15.0	15.0	-0-	-0-	
2	5	5	74.5	68.5	13.0	17.1	17.0	7.05	7.7	7.5	8.1	3.6	2.5	.6	.6	15.0	15.0			KMnO4 BREAK THROUGH IN EFFLUENT
3	5	5	82	76	13.5	17.0	17.0	7.05	7.7	8.0	8.5	3.9	2.6	.6	.6	15.0	15.0			FILTERS A & B BACKWASHED AT 3.75 HRS.
5	5	5	49.75	45.5	13.0	17.2	17.4	7.3	7.5	7.7	8.3	5.6	4.7	.6	.6	15.0	15.0	↓	↓	RESTARTED AT HOUR 4. SHUT-DOWN A RESULT
				AVG.	13.9	17.1	17.2	7.18	7.58	7.65	8.3	4.3	2.7							OF RISING TURBIDITY, EVEN AFTER BACKWASH

LOCATION UVWPP - OREM, UTAH

DATE 31 AUGUST 84

TESTING PERIOD 5

TIME	FILTER OPERATION				PHYSICAL & CHEMICAL CHARACTERISTICS									CHEMICALS ADDED (mg/1)						COMMENTS
	FLOW RATE*		HEADLOSS (in.)		TEMP. °C			pH			TURB. (NTU)			$KMnO_4$		ALUM		POLYMER		* gpm/ft^2 THIS DATA WAS NOT USED, BECAUSE OF TURBIDITY METER.
(hrs.)	A	B	A	B	RAW	A	B	RAW	A	B	RAW	A	B	A	B	A	B	A	B	
1	5	5	31.5	50.5	14.8	22.0	22.0	7.5	7.8	7.82	8.4	1.2	.87	.3	.3	15.0	15.0	-0-	-0-	
2	5	5	40.5	55	14.1	18.0	18.0	7.1	7.4	752	8.4	1.5	2.0	.3	.3	15.0	15.0	↓	↓	
3	5	5	47.5	62	13.8	17.0	18.0	7.83	7.79	7.89	17.0**	3.0	2.9	.3	.3	15.0	15.0			TURBIDIMETER WOULD NOT ZERO ON 1000 std.
4	5	5	52	69.5	13.2	17.5	17.8	7.49	7.70	7.62	~	2.5	2.7	.3	.3	15.0	15.0			TURB. METER FAILURE $KMnO_4$ VISIBLE IN EFF. A & B
																				** UVWPP LAB WAS READING A RAW TURB OF 11.0 NTU

LOCATION UVWPP ~ OREM, UTAH

DATE 1 SEPTEMBER 84

TESTING PERIOD 6

TIME	FILTER OPERATION				PHYSICAL & CHEMICAL CHARACTERISTICS									CHEMICALS ADDED (mg/l)						COMMENTS * gpm/ft²
	FLOW RATE*		HEADLOSS (in.)		TEMP. °C			pH			TURB. (NTU)			$KMnO_4$		ALUM		POLYMER		STARTED USE OF THE UVWPP HACH TURB. METER - TO CONTINUE
(hrs.)	A	B	A	B	RAW	A	B	RAW	A	B	RAW	A	B	A	B	A	B	A	B	
1	5	5	47.5	47	13.5	17.5	17.5	7.43	7.68	7.70	10.8	3.65	4.6	-0-	-0-	15	15	-0-	-0-	USE UNTIL END OF PROJECT.
2	5	5	59.5	53	14.0	17.5	17.8	7.3	7.72	7.7	10.35	2.1	2.4			15	15			
3	5	5	67	63	14.5	17.0	17.2	7.48	7.9	8.1	9.4	1.7	1.7			15	15			
4	5	5	78	74	14.0	17.0	19.0	7.55	7.63	7.6	10.4	1.3	1.68			15	15			
5	5	5	82.5	79.5	13.8	16.5	16.8	7.53	7.78	7.81	10.3	1.4	1.66			15	15			
6	5	5	94.5	89	14	16.7	16.9	7.55	7.82	7.9	10.3	1.42	1.57			15	15			VISIBLE FLOC IN BOTH EFFLUENTS. TERMINAL HEADLOSS REACHED.
				Avg.	14.0	17.0	17.5	7.47	7.76	7.80	10.3	1.93	2.27							

LOCATION UVWFP – OREM, UTAH

DATE 2 SEPTEMBER 84

TESTING PERIOD 7

TIME	FILTER OPERATION				PHYSICAL & CHEMICAL CHARACTERISTICS									CHEMICALS ADDED (mg/1)						COMMENTS
	FLOW RATE*		HEADLOSS (in.)		TEMP. °C			pH			TUPB. (NTU)			KMnO,		ALUM		POLYMER		* gpm/ft²
(hrs.)	A	B	A	B	RAW	A	C	RAW	A	B	RAW	A	B	A	B	A	B	A	B	
1	5	5	60	54	13.2	17.8	18.0	7.49	7.8	7.75	12.0	2.8	1.12	-0-	-0-	10	20	-0-	-0-	
2	5	5	66.25	65.5	13.2	16.5	17.0	7.43	7.7	7.62	11.5	3.7	1.3	↓	↓	10	20	↓	↓	
3	5	5	73.5	76	13.3	16.0	16.6	7.45	7.59	7.73	11.1	3.4	1.05	↓	↓	10	20	↓	↓	VISIBLE FLOC B @ HR 4
4	5	5	82	87	13.8	16.2	16.2	7.39	7.70	7.61	11.2	3.1	.89	↓	↓	10	20	↓	↓	TERMINAL HEADLOSS REACHED - SYSTEM B
5	5	5	89	—	13.3	17.0	—	7.39	7.78	—	10.9	2.6	—	↓	↓	10	—	↓	↓	TERMINAL HEADLOSS
				AVG.	13.4	16.7	16.9	7.43	7.71	7.68	11.3	3.12	1.09							REACHED SYSTEM A 5.5 HRS.

LOCATION UVWPP ~ OREM, UTAH

DATE 8 SEPTEMBER 84

TESTING PERIOD 8

TIME	FILTER OPERATION				PHYSICAL & CHEMICAL CHARACTERISTICS									CHEMICALS ADDED (mg/l)						COMMENTS
	FLOW RATE*		HEADLOSS (in.)		TEMP. °C			pH			TURB. (NTU)			$KMnO_4$		ALUM		POLYMER		* gpm/ft²
(hrs.)	A	B	A	B	RAW	A	B	RAW	A	B	RAW	A	B	A	B	A	B	A	B	
1	5	5	52.25	43.25	13.6	17.0	17.2	7.71	8.03	7.98	22.0	.29	1.88	-0-	-0-	6.7	9.4	.67	.81	TARGET DOSING FOR BOTH A & B WAS
2	5	5	60.0	56.0	13.8	16.5	16.3	7.65	7.90	7.84	21.0	.11	1.75			6.7	9.4	.67	.81	ALUM = 8.1 mg/l polymer = .70 mg/l
3	5	5	76.0	66.0	13.5	16.5	16.3	7.69	7.93	7.97	21.0	.09	2.10			6.7	9.4	.67	.81	
4	5	5	84.0	70.0	13.9	16.4	16.3	7.70	8.00	7.85	22.0	.12	2.20			6.7	9.4	.67	.81	SYSTEM A SHUT DOWN AT 4.5 HRS. ~ TERMINAL
5	5	5	—	80.0	14.5	—	16.8	7.89	—	7.91	22.0	—	2.0			6.7	9.4	.67	.81	HEADLOSS REACHED ≅ 98"
6	5	5	—	85.25	15.0	—	17.0	7.70	—	7.85	21.0	—	3.0			6.7	9.4	.67	.81	
7	5	5	—	93.0	15.0	—	16.9	7.73	—	7.81	21.0	–	3.5			6.7	9.4	.67	.81	SYSTEM B SHUT DOWN AT 7 HRS. ~ TERMINAL
				Avg.	14.2	16.6	16.7	7.72	7.97	7.89	21.4	0.15	2.35							HEADLOSS REACHED ≈ 93"
																				CHEMICAL PUMPS DO NOT MAINTAIN A CONSISTENT
																				FLOW

LOCATION UVWPP ~ OREM, UTAH

DATE 9 SEPTEMBER 84

TESTING PERIOD 9

TIME	FILTER OPERATION				PHYSICAL & CHEMICAL CHARACTERISTICS									CHEMICALS ADDED (mg/l)						COMMENTS
	FLOW RATE*		HEADLOSS (in.)		TEMP. °C			pH			TURB. (NTU)			$KMnO_4$		ALUM		POLYMER		* gpm/ft^2
(hrs.)	A	B	A	B	RAW	A	B	RAW	A	B	RAW	A	B	A	B	A	B	A	B	
1	5	5	64	54	14.0	17.5	17.9	7.80	7.92	7.87	24	.90	2.2	-0-	-0-	8.91	3.44	.988	.281	
2	5	5	74	60	13.6	17.0	17.0	7.80	8.0	8.0	24	1.25	2.5	↓	↓	8.91	3.44	.988	.281	VISIBLE FLOC IN EFFLUENT SAMPLES, HR 2.
3	5	5	86.5	68.5	14.0	17.0	17.0	7.72	7.96	7.99	24	1.93	2.76	↓	↓	8.91	3.44	.988	.281	
4	5	5	93	76	15.0	16.9	16.9	8.0	8.1	7.99	23	6.0	3.0	↓	↓	8.91	3.44	.988	.281	
				AVG.	14.2	17.1	17.2	7.83	8.00	7.96	23.8	2.52	2.62							TARGET VALUES FOR BOTH SYSTEMS A & B
																				ALUM ⇒ 8.1 mg/l POLYMER ⇒ .72 mg/l
																				CHEMICAL PUMPS VARIED

LOCATION UVWPP ~ Orem, Utah

DATE 18 September 84

TESTING PERIOD 10

TIME	FILTER OPERATION				PHYSICAL & CHEMICAL CHARACTERISTICS									CHEMICALS ADDED (mg/l)						COMMENTS
	FLOW RATE*		HEADLOSS (in.)		TEMP. °C			pH			TURB. (NTU)			$KMnO_4$		ALUM		POLYMER		* gpm/ft²
(hrs.)	A	B	A	B	RAW	A	B	RAW	A	B	RAW	A	B	A	B	A	B	A	B	
1	5	5	68.0	53.5	14.0	16.8	17.0	7.67	7.90	7.90	22.0	.62	.52	-0-	-0-	7.5	8.08	.53	.70	
2	5	5	73.0	58.0	14.0	17.3	17.4	7.75	7.99	7.90	23.0	.38	.36	↓	↓	7.5	8.08	.53	.70	
3	5	5	70.5	72.0	14.0	17.8	17.5	7.71	7.93	8.0	24.0	.33	.52	↓	↓	7.5	8.08	.53	.70	FLOC VISIBLE IN SYSTEM B EFFLUENT ~HR 3
4	5	5	88.0	74.5	14.0	17.1	17.2	7.73	8.01	7.99	23.0	1.35	1.34	↓	↓	7.5	8.08	.53	.70	FLOC VISIBLE IN BOTH SYSTEMS' EFFLUENT
5	5	5	88.0	88.5	15.0	17.0	17.1	7.81	8.1	7.90	22.0	6.6	2.2	↓	↓	7.5	8.08	.53	.70	" "
				Avg.	14.2	17.2	17.2	7.73	7.99	7.94	22.8	1.86	0.99							TERMINAL HEADLOSS APPROACHING AND RISING
																				TURB REASON FOR SHUT-DOWN.
																				TARGET CHEMICAL DOSES FOR BOTH A & B =>
																				ALUM - 8.01 mg/l POLYMER - .70 mg/l

LOCATION UVWPP ~ OREM, UTAH

DATE 19 SEPTEMBER 84

TESTING PERIOD II

TIME	FILTER OPERATION				PHYSICAL & CHEMICAL CHARACTERISTICS									CHEMICALS ADDED (mg/l)						COMMENTS
	FLOW RATE*		HEADLOSS (in.)		TEMP. °C			pH			TURB. (NTU)			$KMnO_4$		ALUM		POLYMER		* gpm/ft²
(hrs.)	A	B	A	B	RAW	A	B	RAW	A	B	RAW	A	B	A	B	A	B	A	B	
1	5	4	60.0	52.5	14.5	18.0	18.2	7.68	7.99	8.0	12.6	.50	.42	-0-	-0-	7.66	7.57	1.24	1.28	TARGET VALUES FOR CHEMICALS FOR A & B
2	5	4	69.0	56.0	14.3	17.8	17.9	7.72	8.03	8.05	13.6	.27	.17			7.06	7.57	1.24	1.28	ALUM => 8.1 mg/l POLYMER => 1.44 mg/l
3	5	4	76.5	62.0	14.1	17.7	17.9	7.75	8.03	8.03	14.8	.24	.17			7.06	7.57	1.24	1.28	
4	5	4	84.0	68.0	14.1	17.8	17.9	7.75	8.01	7.99	16.7	.22	.16			7.06	7.57	1.24	1.28	
5	5	4	89.0	72.5	14.1	17.9	18.0	7.80	8.01	8.01	16.5	.23	.17			7.06	7.57	1.24	1.28	SMALL AMOUNT OF FLOC VISIBLE IN BOTH
6	—	4	—	81.0	15.0	—	18.4	7.73	—	8.02	17.6	—	.19			7.06	7.57	1.24	1.28	SYSTEMS' EFFLUENT HR 5.
7	—	4	—	86.0	15.0	—	17.9	7.77	—	8.03	16.9	—	.19	↓	↓	7.06	7.57	1.24	1.28	SYSTEM A SHUT DOWN AT 5.75 HR. DUE TO
				Avg.	14.4	17.8	18.0	7.74	8.01	8.02	15.5	0.29	0.21							TERMINAL HEADLOSS
																				RESIDUAL ALUMINUM HR 2 –
																				EFFLUENT A - 267 ug/l EFFLUENT B - 199 ug/l
																				RAW - 145 ug/l
																				RESIDUAL ALUMINUM SHUT-DOWN –
																				EFFLUENT A - 300 ug/l EFFLUENT B - 268 ug/l
																				RAW - 218 ug/l

LOCATION UVWPP ~ Orem, Utah

DATE 26 September 84

TESTING PERIOD 12

TIME	FILTER OPERATION				PHYSICAL & CHEMICAL CHARACTERISTICS									CHEMICALS ADDED (mg/l)						COMMENTS
	FLOW RATE		HEADLOSS (in.)		TEMP. °C			pH			TURB. (NTU)			KMnO$_4$		ALUM		POLYMER		* gpm/ft²
(hrs)	A	B*	A	B	RAW	A	B	RAW	A	B	RAW	A	B	A	B	A	B	A	B	
1	4	4	42.0	49.0	14.4	18.0	18.1	7.78	8.12	8.08	11.6	.50	.42	-0-	-0-	3.33	8.26	1.31	1.45	
2	4	4	55.0	48.0	14.0	17.3	17.5	7.81	8.09	8.05	11.4	.33	.20			3.33	8.26	1.31	1.45	Small amounts of floc visible
3	4	4	60.5	55.5	14.1	18.0	17.0	7.81	8.12	8.03	11.3	.24	.12			3.33	8.26	1.31	1.45	
4	4	4	67.0	56.0	14.5	16.8	16.9	7.80	6.11	8.08	11.9	.19	.10			3.33	8.26	1.31	1.45	
5	4	4	71.5	61.0	14.0	17.0	17.2	7.70	8.19	8.00	13.0	.18	.10			3.33	8.26	1.31	1.45	
6	4	4	81.0	74.0	14.6	16.3	16.4	7.66	8.15	8.01	14.6	.16	.12			3.33	8.26	1.31	1.45	
7	4	4	88.0	71.5	14.0	16.8	17.0	7.61	8.15	8.10	15.5	.16	.10			3.33	8.26	1.31	1.45	
8	4	4	96.0	74.5	14.2	16.2	16.4	7.59	8.11	8.02	16.6	.16	.11			3.33	8.26	1.31	1.45	Terminal headloss ~ System A
9	4	4	—	91.0	14.0	—	16.9	7.56	—	7.99	16.2	—	.15	↓	↓	3.33	8.26	1.31	1.45	Terminal headloss ~ System B
				Avg.	14.2	17.1	17.0	7.70	8.13	8.04	13.6	0.24	0.16							
																				Target Values for Chemicals:
																				A - Alum => 4.05 mg/l Polymer => 1.44 mg/l
																				B - Alum => 3.1 mg/l Polymer => 1.44 mg/l

LOCATION UVWP – OREM, UTAH

DATE 27 SEPTEMBER 84

TESTING PERIOD 13

TIME	FILTER OPERATION				PHYSICAL & CHEMICAL CHARACTERISTICS									CHEMICALS ADDED (mg/l)						COMMENTS
	FLOW RATE*		HEADLOSS (in.)		TEMP. °C			pH			TURB. (NTU)			KMnO$_4$		ALUM		POLYMER		* gpm/ft^2
(hrs.)	A	3	A	B	RAW	A	B	RAW	A	B	RAW	A	B	A	B	A	B	A	B	
1	3	4	38.0	40.0	14.1	17.0	16.8	7.60	8.09	8.01	15.5	.57	.48	-0-	-0-	3.47	4.41	1.27	2.19	TARGET CHEMICAL DOSE FOR BOTH SYSTEMS
2	3	4	46.0	43.5	14.2	17.0	16.9	7.60	8.10	8.10	15.4	.36	.27			3.47	4.41	1.27	2.19	ALUM => 4.05 mg/l POLYMER => 1.44 mg/l
3	3	4	48.75	49.25	14.3	16.6	16.5	7.49	8.15	8.09	16.4	.30	.22			3.47	4.41	1.27	2.19	
4	3	4	57.25	53.50	14.0	16.4	16.5	7.69	8.09	8.09	18.8	.25	.21			3.47	4.41	1.27	2.19	
6	3	4	54.25	64.0	14.0	17.1	16.7	7.51	8.04	8.04	19.5	.23	.19			3.47	4.41	1.27	2.19	VARIABLE FLOW ON SYSTEM A FILTER PUMP
7	3	4	65.0	71.0	14.0	16.5	16.5	7.52	8.05	8.10	19.8	.19	.17			3.47	4.41	1.27	2.19	
8	3	4	59.5	76.0	14.0	16.7	16.8	7.60	8.10	8.04	19.8	.19	.16			3.47	4.41	1.27	2.19	SYSTEM A EXPERIENCED SHOCK LOADING TO FILTER & VARIANCE IN HEADLOSS DATA
9	3	4	88.0	82.5	14.0	16.8	16.8	7.60	8.10	8.09	21.0	.16	.54			3.47	4.41	1.27	2.19	
10	–	4	—	84.0	14.0	—	16.8	7.60	—	8.15	18.6	—	.32			—	4.41	—	2.19	
11	–	4	—	91.0	14.3	—	16.8	7.52	—	8.07	18.0	—	.16			—	4.41	—	2.19	SMALL AMOUNT OF FLOC VISIBLE IN EFFLUENT OF B
				Avg.	14.1	16.8	16.7	7.57	8.09	8.08	18.3	0.28	0.27							
																				CHEMICAL PUMPS WERE OFF AT HOUR 9 FOR APPROX. 15 MINUTES.

LOCATION UVWPP ~ Orem, Utah

DATE 28 September 84

TESTING PERIOD 14

TIME	FILTER OPERATION				PHYSICAL & CHEMICAL CHARACTERISTICS									CHEMICALS ADDED (mg/l)						COMMENTS
	FLOW RATE*		HEADLOSS (in.)		TEMP. °C			pH			TURB. (NTU)			KMnO$_4$		ALUM		POLYMER		* gpm/ft^2
(hrs.)	A	B	A	B	RAW	A	B	RAW	A	B	RAW	A	B	A	B	A	B	A	B	
1	3	4	40.5	51.5	14.4	17.1	17.0	7.69	8.20	8.19	10.2	.38	.44	-0-	-0-	3.89	2.14	1.35	1.54	Target Chemical Dose A: alum - 4.05 mg/l
3	3	4	49.5	65.0	14.5	17.0	16.8	7.62	8.15	8.11	10.7	.25	.24			3.89	2.14	1.35	1.54	Polymer - 1.44 mg/l
4	3	4	54.5	73.0	14.6	17.1	17.0	7.61	8.12	8.11	10.7	.20	.17			3.89	2.14	1.35	1.54	B/ alum - 2.03 mg/l Polymer - 1.44 mg/l
5	3	4	60.0	81.0	14.8	17.5	17.1	7.60	8.12	8.10	15.3	.17	.16			3.89	2.14	1.35	1.54	
7	3	4	69.0	93.5	14.5	17.1	16.9	7.61	8.21	8.12	15.8	.17	.16			3.89	2.14	1.35	1.54	Floc visible in system A&B effluent
8	3	—	66.0	—	15.1	16.8	—	7.60	8.20	—	17.9	.15	—			3.89	—	1.35	—	Terminal headloss reached for system B
9	3	—	62.0	—	14.5	17.0	—	7.80	8.20	—	18.3	.29	—			3.89	—	1.35	—	
10	3	—	78.0	—	14.0	17.2	—	7.61	8.20	—	19.9	.23	—	↓	↓	3.89	—	1.35	—	Visible floc ⇒ oscillating turb.
				Avg.	14.6	17.1	17.0	7.64	8.18	8.13	14.85	0.23	0.23							readings.