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# Development of Design Criteria for Individual Domestic Water Supplies from Surface Impoundments

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by

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ABSTRACT

Model and prototype studies were conducted on various filter media for use in an automated filter for individual domestic water supplies. The various media included six sands of varying effective diameters and uniformity coefficients, ground and sized walnut shells, a mixture of sand and coal, and paraffin wax beads. The filter consisted of an upflow arrangement with a flocculating and settling portion in the bottom three feet, a one foot filtering section and a three foot section for clean water storage at the top above the filter. Backwashing was accompolished by opening a valve at the bottom of the filter. This allowed the clean water to flow downward through the filter by gravity. This water washed the mud from the bottom face of the filter and removed the flocculated clays from the bottom section.

The best results were obtained from beaded paraffin wax which had a specific gravity less than water. It was necessary to place screens above and below the filter. Runs on the three foot diameter prototype which had a capacity of seven gallons per minute produced water meeting the standards of the USPHS. This prototype should produce acceptable drinking water and requires a minimum of construction labor and operating supervision.



KEYWORDS: flocculation*, filtration, water treatment, surface waters, automation, filters

*engineering design

# Development of Design Criteria for Individual Domestic Water Supplies from Surface Impoundments

Many rural homes, cabins on lakes, or other residences remote from community water supplies do not have a satisfactory source of ground water for domestic use. In recent years, researchers at this and other universities have developed slow sand filtration systems which enable the utilization of surface water supplies for household use. Waters from such impoundments are usually quite turbid and require filtering and purifying.

The slow sand filters which have been developed call for construction and operational skills not usually possessed by the operator. This project is directed toward the development of design criteria for an automated, packaged filtering plant adapted to individual household needs.

Present Practices. - Municipal water plants in treating surface water use three steps: (1) Settling; (2) Filtration; (3) Storage.

A flocing agent such as alum is added to the raw water at a rate of some 30 ppm or more based on a previous analysis of the water. This chemical is first rapidly mixed some 5 minutes and then slowly mixed for some 30 minutes to one hour. The water then flows slowly through the settling basin during which time, under optimum conditions, most of the turbidity or muddiness settles out.

This water is then allowed to flow down through a filter media of sand or sand and coal (anthrafilt) at approximately 2 gallons per minute per square foot. The mud that didn't settle out collects on the filter surface. As this mud-deck thickens, more pressure or head is needed to maintain a desired flow through the filter. The mud is then removed by reversing the flow of water and increasing its velocity to one and one-half to two feet rise per minute. This causes the filter bed to "fluff" up to approximately twice its normal depth and washes the mud away. On a continuous-use filter this back washing is needed approximately every 24 hours depending upon how well the mud settled in the sedimentation basin. This method is known as open gravity filtering.

This same principal was previously used by Oklahoma State University to develop a system. The down flow rate was reduced to 50 gallon per day per square foot and the settling basin was correspondingly increased in size. With this system when the mud-deck needs removing the water level was lowered below the upper sand surface. Then some two inches of mud and sand is manually removed with a shovel.

At this slow filtering rate the filter is usually nine feet square or larger. To back wash a filter of this size would require a pump of at least ninety gallons per minute. Apparently, back washing a filter helps to scrub the sand particles clean and removes any mud balls that tend to form. After several skimmings the filter media is replenished. In field studies using this down flow system, it was observed that often the user was busy and instead of "skimming" the filter surface, would take a rod and penetrate the filter vertically in several places. This would increase the flow rate temporarily, but would cause the filter to become muddy internally. Eventually, clean sand would be needed to replace the entire bed.

O.S.U. has conducted field research on another type commonly known as pressure filtration. In this system, both the filter and settling basin are each completely encased in closed cylinders. Using a closed system such as this permits the use of only one pump instead of two. No concrete structure is needed for the settling basin, sand filter, and storage.

Usually, the entire system may be installed in one day compared to several days when using concrete. Water system contractors prefer the pressure filtration as there is more net profit in such an installation. Less settling time and higher flow rates are used. Back washing is less frequent as 25 to 45 feet of head (pressure) may be maintained on the filter compared to 4 to 5 feet used in municipal gravity systems. As a result the unit takes less abuse, requires more precise operation, and many users fail in this respect.

Accordingly, the Oklahoma Department of Health does not approve a pressure filtration system. Within the last year the Oklahoma Department of Health is cooperating with one of our Oklahoma municipal water plants and have planned some studies to reduce the settling time to some 20 minutes instead of one hour or more. Should this prove satisfactory, the water plant investment will be substantially reduced. Previous research studies of surface water treatment for domestic purposes by the Agricultural Engineering Department resulted in satisfactory filtration after a 20 minute settling period.

<u>Experimental Equipment and Procedure</u>. - In the study just completed, various combinations of sand media as well as other media such as coal, glass beads, walnut shells, and pelleted paraffin wax were studied. The study utilized six model filters made of 4-inch diameter and 72-inch long plastic tubing, figures 1 and 2. This clear plastic tubing provides an opportunity to observe results. Each unit used an individual flow meter for the raw water and for the flocculant (alum) aid. Each unit also had its own sight meter to measure the head necessary to maintain the desired flow. At the beginning of the studies, it was found that flow rate should be measured - - before alum was added. Otherwise, the floc clumps would cause an uneven flow rate through the rota-flow meter with resulting inaccurate readings. In early attempts to use one

chemical feeder for the six models, after several hours of operation, the head on the various filter media would vary. This, in turn, varied the individual chemical flow to each model filter. Individual alum solution feeders were then used for each model filter.

The self-contained unit was trailor mounted. On-site studies of some 12 ponds were made. Transporting different pond waters to our campus laboratory proved not to be practical because of the volumes of water involved. It was also found that the characteristics of the transported water would change while being transported. Therefore, the experimental filters were taken to the water supplies.

The on-site study began with a jar test consisting of six two-liter containers of raw water. Varying amounts of coagulant aid were added to these containers. The feed-rate of coagulant was then determined by the settlement obtained in these jars after 10 minutes. High turbid and low turbid waters required approximately the same amounts of coagulant aid. The results indicate that slightly higher feed rates of coagulant aid are needed in the model studies than those used by the municipal plant. This parallels the results on previous gravity and pressure treatment studies.

The flow rate through the model filters was limited to one gallon per minute per square foot which is one-half of the municipal rate. Filter depths of three inches, six inches, nine inches, twelve inches, and eighteen inches were studied. Only the 12-inch depth of the filter is reported in detail.

All filter media in each of the model filters had been previously used and backwashed several times. As noted in figure 2, all filters used the same raw water source which had a pH range of 8.1 to 8.4; an alkalinity range of 142 ppm to 147 ppm; hardness range of 170 ppm to 176 ppm; and a turbidity range of 23 ppm to 28 ppm.

Each filter was adjusted separately to flow at the rate of one gallon per minute per square foot. The studies indicate the preflocculated water is difficult to control at a constant flow rate through the small rotometer flow meters. Recording of running time began after the finished water began to flow from the outlet, figure 5. As the mud deck accumulated on the lower side of the filter media, the permeability decreased and the value of $h_2$ increased. (See figure 5). The six runs reported were each of 23 hours duration. Filter media were as follows: No. 1 = pelleted paraffin wax; No. 2 = anthrafilt and sand; No. 3 = No. 3 sand (see figure 3); No. 4 = No. 4 sand (see figure 3); and No. 5 = walnut shells.

Results. - Turbidity in the finished water in excess of 5 ppm was considered undesirable. A major influencing factor in finished water turbidity apparently was the proper coagulation of the raw water just prior to filtering. Using a separate chemical feeder for each filter made like coagulations difficult. Too much coagulant aid caused the model filter media permeability to decrease.

Some 12 to 19 inches of finished water was sufficient to properly backwash each filter. A run of 23 hours continuous operation required 0.5 percent to 0.9 percent of output as compared to some 5 percent used in a municipal water treatment plant. The maximum turbidity of the finished water (figure 7) occurred sometimes at the beginning and at other times during the middle or at the end of a run and did not follow a set pattern. It appears that the coagulation was a major factor in the turbidity of the filtered water and apparently caused this variation.

Little difference in the turbidity of the filtered water was noted for the three-inch, six-inch, nine-inch, twelve-inch, and eighteen-inch depths of filter media.

In general, the numbers 1 and 2 model sand filter media gave slightly better results than the number 5 and number 6 models. As the mud deck built up on the lower side of the filter media, the 1 and 2 media would sometimes rise en masse in the plastic tubes. At other times, a channeled flow would develop through portions of the filter and an undesirable turbidity would result in the filtered water.

The 3 and 4 sand filter media operated with less trouble before backwashing; however, results were more erratic. Also, when optimum flocculation did not occur, turbidity increased in the finished water.

The mean turbidity range for filter media number 3, number 4, paraffin, and the sand and coal did not vary greatly, as shown in figure 8. The walnut shell used ranged in size from 100 mesh to 35 mesh with the larger sizes predominating. This large particle size appears to account for higher turbidities using this media.

Prototype Unit. - The 36-inch diameter prototype unit has a continuous flow rate of 7.1 gallons per minute calculated at 1 gpm per square foot (see figure 7). Should the demand on the unit exceed this flow rate, there is a reserve of about 150 gallons in the upper area. The unit is so automated that should this reserve be used up, the water level goes down to float F4 (figure 7), and the pump stops until the level reaches F3. This will take about 7 minutes.

The unit is designed so that once a week a time clock will disconnect the raw water pump and operate the backwash valve $V_3$ during an early morning off-peak period. Finished water will flow back through the filter until the level at float F2 is reached. The time clock will prevent the raw water pump P from running for some 20 minutes until the mud deck has had time to completely settle to the bottom. For a normal weekly backwashing, the backwashing requirement is 5 to 8 percent of the finished water requirements.

Should the capacity of this unit be inadequate, one or more similar units could be added in parallel. Another solution would be to allow this one unit to operate some 23 hours per day (allowing 2 thirty-minute backwashing periods per day) and store the finished water in a cistern. The house pump (P2) would then be located at the cistern. A 23-hour run on this unit would produce 9,800 gallons per day. This would be equivalent to about 2 1/2 months water supply for the average residential family of five.

An alternate plan would be to use plywood tanks of a larger capacity that could be transported disassembled through doors. This would also help overcome the problem of getting the tanks through small doors. Strengthening of the floor of the room in which the tank is located may be necessary as a three-foot square tank of water seven feet tall weighs almost two tons.

## Summary and Conclusions

Model Units. -

1. Experiments were conducted on various filter media in 4-inch Lucite cylinders to determine their performance as upflow filters.

2. The individual runs were conducted for 23 hours which is equivalent to about 2 1/2 months of household use for a 3-foot prototype.

3. The medium sand with uniformity coefficients of 1.5 and 2.0 gave satisfactory results.

4. Pelleted paraffin wax (Union Oil Company) also gave satisfactory results. As this material has a specific gravity of less than 1.0, it lends itself very well to this type of filter. This requires a screen both above and below the filter media.

5. About 12 inches of backwashing water appears to be needed for each backwashing.

6. Under normal operation backwashing once per week appears adequate and would work well with time clock controls.

7. The backwashing requirement would be about 5 percent of the filtered water requirement.

8. Controls to shut off the filtered water supply which are actuated by low levels of flocculating and chlorinating chemicals would appear desirable.

9. Accurate positive metering of the coagulant aid is essential.

Item I, Prototype unit. - Using wax as a filter media, a series of five preliminary runs of some ten hours each were conducted with the prototype unit. A time clock was used to start and stop the unit at intervals of some 15 minutes each to simulate actual operating conditions. The quality of the resultant finished water in each run fell within the USPH requirements.

Each of these runs represented a normal usage of some 2100 gallons of water, which is equivalent to some 20 days usage for an average family.

In additional runs, Ottawa filter sand having a uniformity coefficient of 1.7 and effective diameter of 0.40were used as a filter media.

The initial run of this media produced acceptable results. However, after the 1st backwash the water would channel up the outer edge of the filter media. The result was water of unacceptable turbidity. Several attempts to correct this problem were not successful.

Future Recommended Studies. - Additional studies using Ottawa filter sand or the equivalent could result in satisfactory results. An incapsulated (epoxy-resin bonded) filter media shows possibilities in this field. This type of filter media would simplify installation and cleaning.

An automated, packaged, upflow filter appears practical and feasible when using wax (unibeads) as a filter media. This filter would be easily constructed, low in cost, effective in producing good quality water, and could be operated by householders with a minimum of technical training. It could be rapidly installed with the skills and tools normally possessed by a water systems dealer.

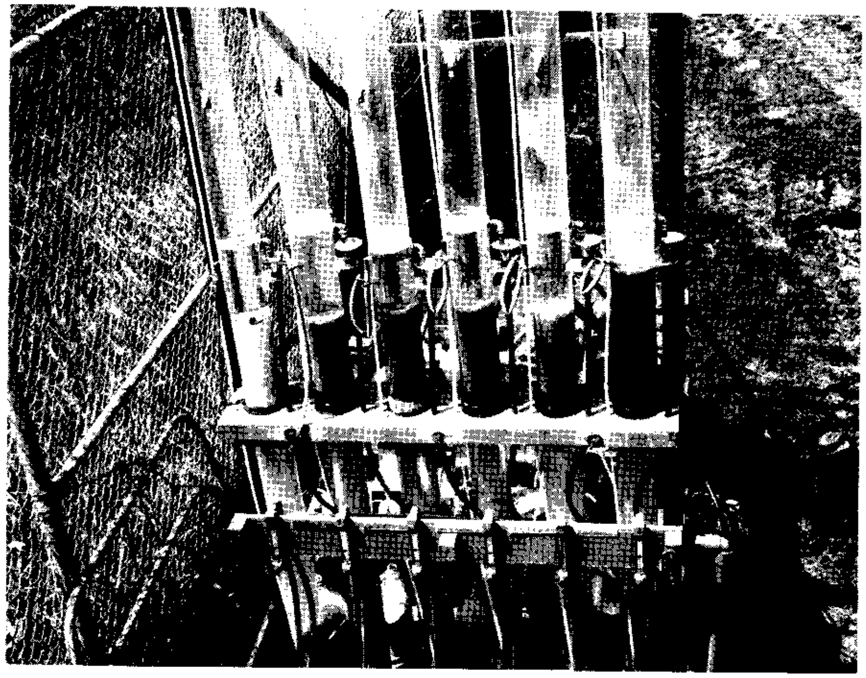


Figure 1. A Close-Up View of the Six Unit Model Filter.

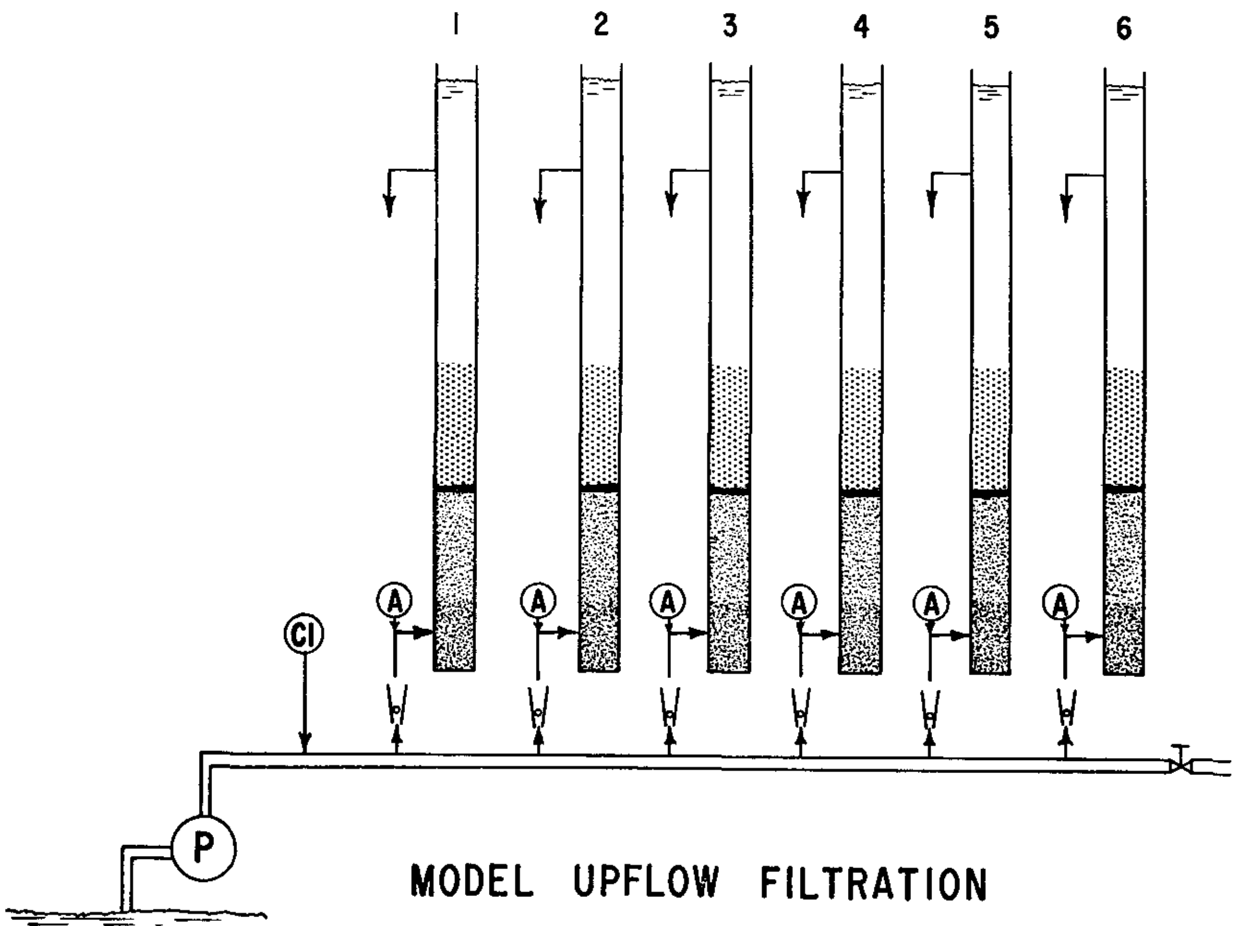
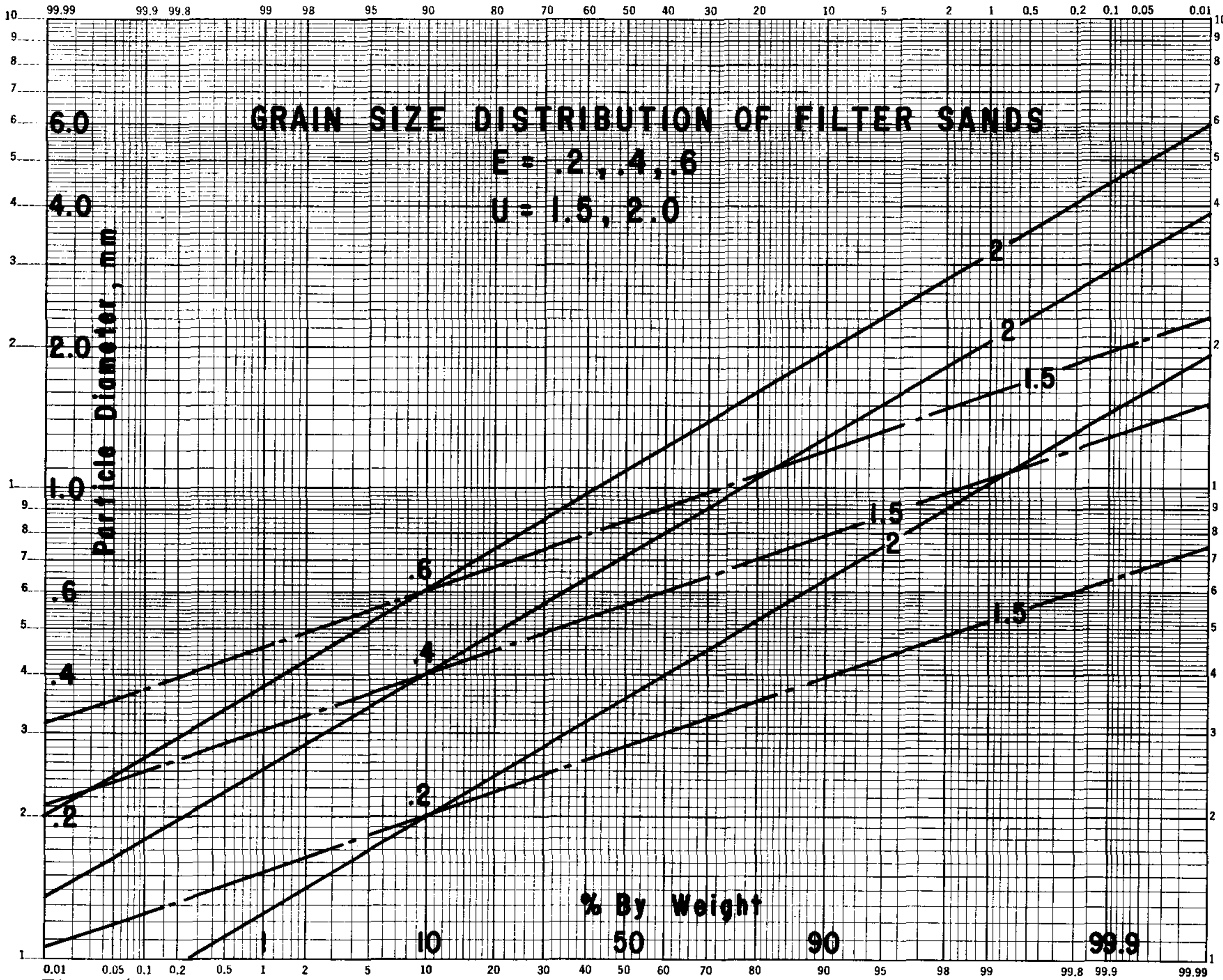



Figure 2.

## (Filter Media) - Sands

| U.S. Sieve Series | | No. 1 Percent | No. 2 Percent | No. 3 Percent | No. 4 Percent | No. 5 Percent | No. 6 Percent |
|---|---|---|---|---|---|---|---|
| Screen Size | E<br>U | .2<br>1.5 | .2<br>2.0 | .4<br>1.5 | .4<br>2.0 | .6<br>1.5 | .6<br>2.0 |
| 80-100 | | 4.5 | | | | | |
| 60-80 | | 29.5 | 15.5 | 0.1 | 1.0 | | .05 |
| 50-60 | | 26.0 | 14.0 | 0.9 | 1.7 | | 0.20 |
| 40-50 | | 34.0 | 29.0 | 13.0 | 9.3 | .4 | 1.75 |
| 35-40 | | 3.5 | 13.0 | 20.0 | 10.0 | 2.1 | 2.50 |
| 30-35 | | 1.3 | 10.0 | 26.0 | 12.0 | 7.9 | 5.50 |
| 20-30 | | .1 | 9.2 | 34.0 | 30.0 | 20.0 | 20.00 |
| 12-20 | | | 1.7 | 6.0 | 33.0 | 53.5 | 54.00 |
| 8-12 | | | | | 2.6 | 12.5 | 12.00 |
| 6-8 | | | | | .4 | 2.4 | 3.90 |
| 4-6 | | | | | | .5 | |

Figure 3. Composition of Filter Sands Studied



GRAIN SIZE DISTRIBUTION OF FILTER SANDS
E = .2, .4, .6
U = 1.5, 2.0
Particle Diameter, mm
% By Weight
6.0
4.0
2.0
1.0
.6
.4
.2
1
10
50
90
99.9

Figure 4.

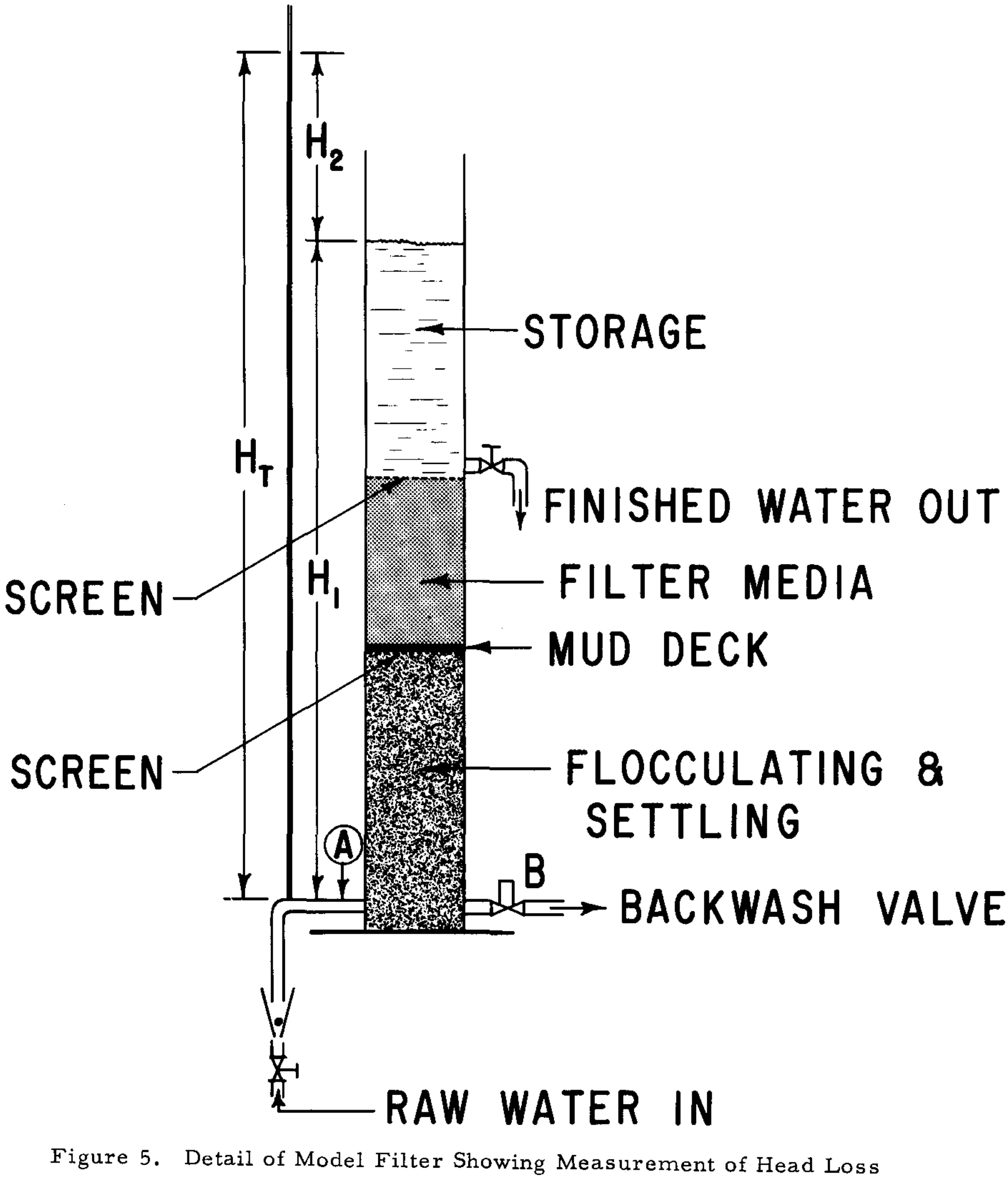



Figure 5. Detail of Model Filter Showing Measurement of Head Loss

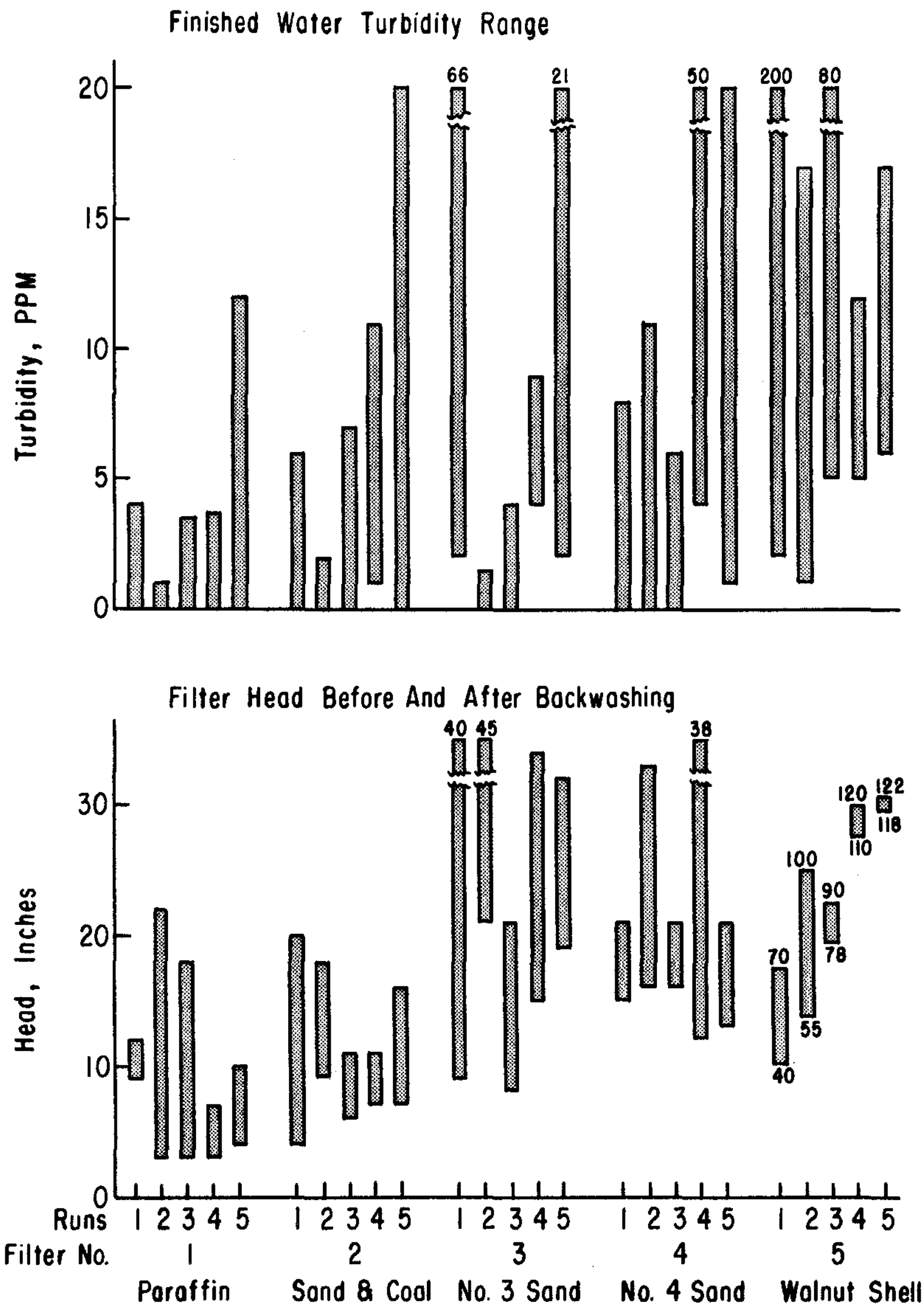



Figure 6. Turbidity and Permeability Relationships

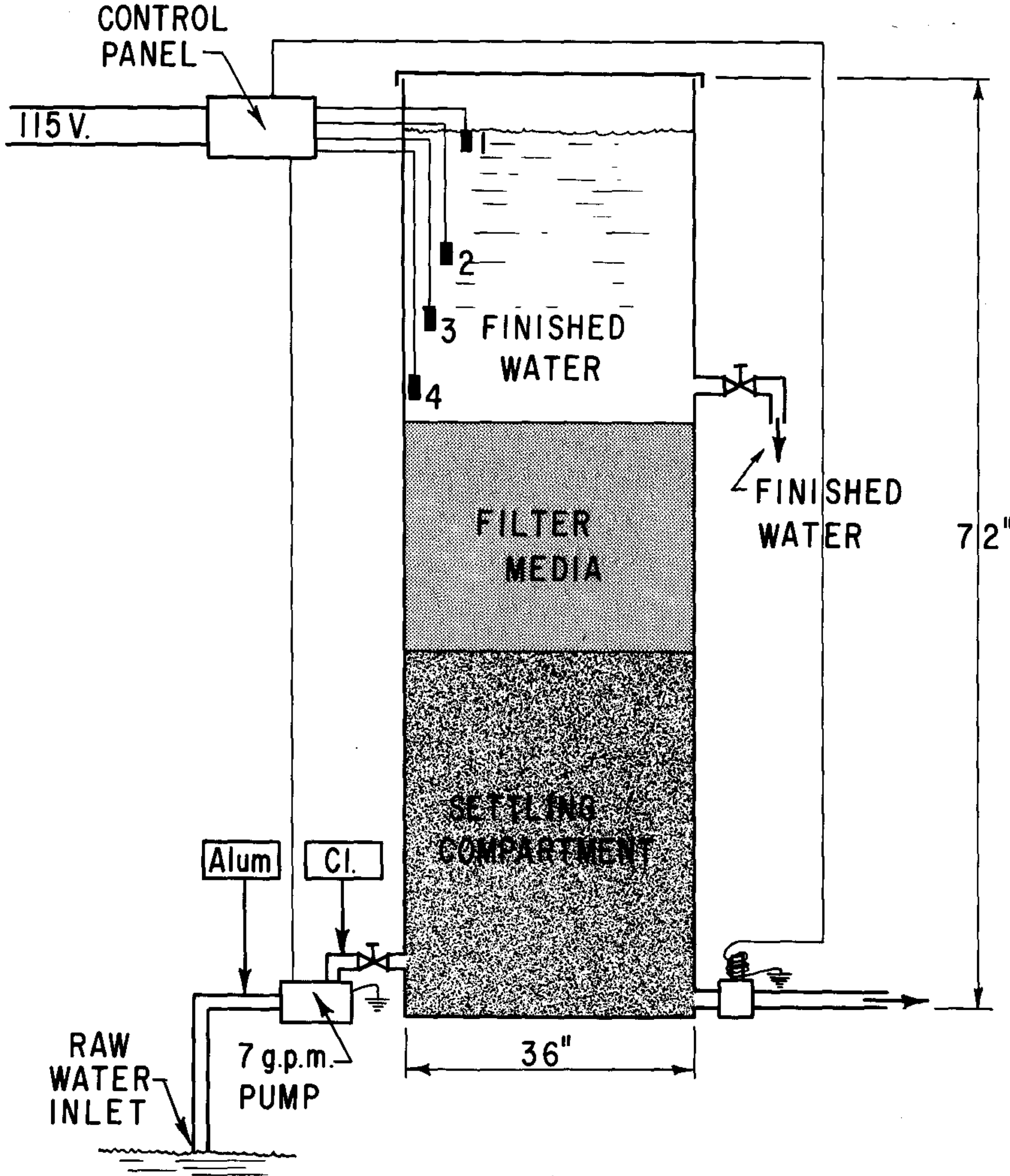



Figure 7. Prototype Treating Plant Designed for gal/min/ft$^2$

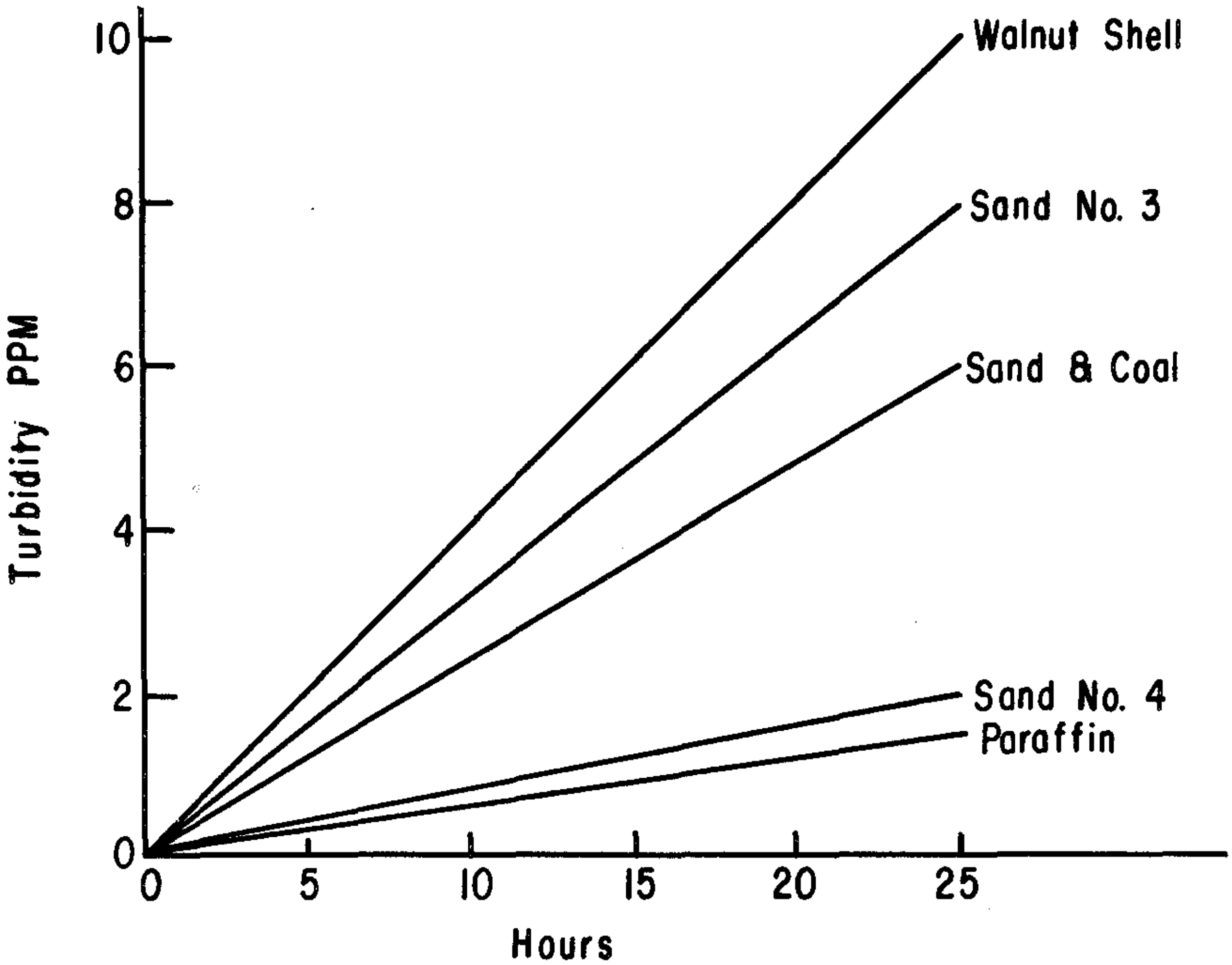



Figure 8. Mean Turbidity Range

## ADDITIONAL MODEL STUDIES WITH PRECISE METERING EQUIPMENT*

### WAX

| Run | H | T | Hrs |
|---|---|---|---|
| 1 | 8.75 | 0 | 10 |
| 2 | 17.5 | 0 | 10 |
| 3 | 16.37 | 0 | 18 |
| 4 | 6.13 | 1 | 40 |
| 5 | 9.00 | 4 | 30 |
| 6 | 23.00 | 4 | 30 |

### SAND & COAL

| Run | H | T | Hrs |
|---|---|---|---|
| 1 | 17.00 | 6 | 10 |
| 2 | 8.75 | 0 | 10 |
| 3 | 12.50 | 10 | 18 |
| 4 | 8.25 | 6 | 40 |
| 5 | 10.87 | 7 | 30 |
| 6 | 15.2 | 7 | 30 |

### #3 SAND

| Run | H | T | Hrs |
|---|---|---|---|
| 1 | 46.00 | 66 | 10 |
| 2 | 44.50 | 1 | 10 |
| 3 | 16.37 | 4 | 18 |
| 4 | 34.25 | 2 | 40 |
| 5 | 32.87 | 26 | 30 |
| 6 | 23.00 | 8 | 30 |

### #4 SAND

| Run | H | T | Hrs |
|---|---|---|---|
| 1 | 13.50 | 0 | 10 |
| 2 | 35.25 | 0 | 10 |
| 3 | 14.82 | 4 | 18 |
| 4 | 38.37 | 1 | 40 |
| 5 | 20 | 7 | 30 |

### WALNUT HULLS

| Run | H | T | Hrs |
|---|---|---|---|
| 1 | 70.12 | 2 | 10 |
| 2 | 98.32 | 10 | 10 |
| 3 | 90.37 | 13 | 18 |
| 4 | 120.75 | 11 | 40 |
| 5 | 120.00 | 14 | 30 |

### CELLULOSE ACETATE

| Run | H | T | Hrs |
|---|---|---|---|
| 1 | 8.50 | 1 | 10 |
| 2 | 12.00 | 0 | 10 |
| 3 | 8.25 | 2 | 18 |
| 4 | 9.75 | 6 | 40 |
| 5 | 4.75 | 17 | 30 |

*H = differential head in inches of water
T = turbidity in parts per million

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