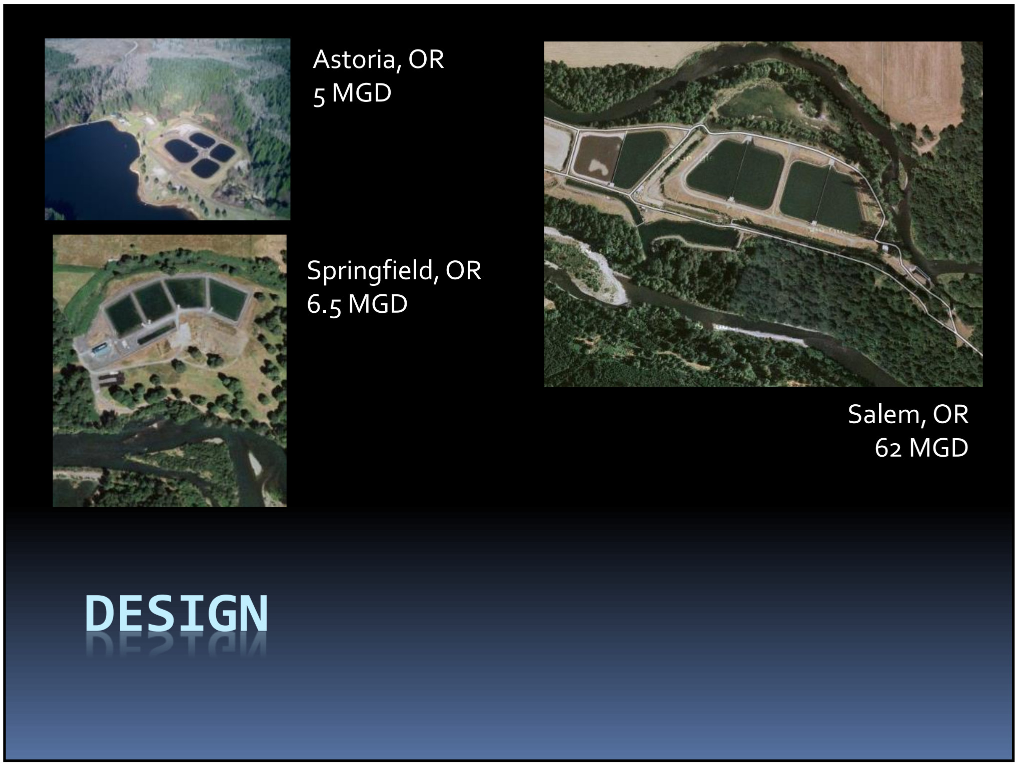
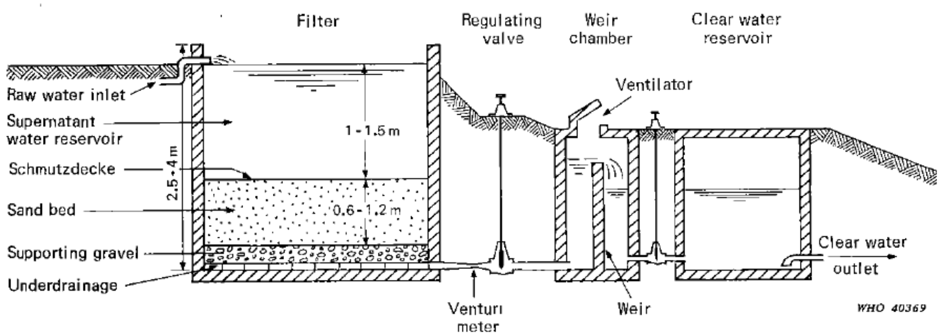


Now we'll get into some design aspects of slow sand filtration. Aerial photo of Astoria, OR (a 5 MGD) was taken by Frank Wolf in 2010. Other photos are from GoogleMaps downloaded in 2013.

GENERAL SCHEMATIC (WHO, 1974)

FIG. 1. DIAGRAM OF A SLOW SAND FILTER

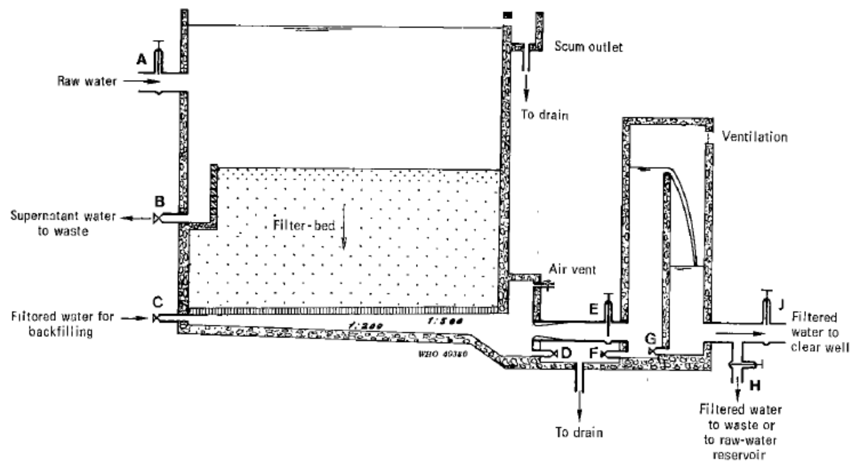


The control devices are shown in greater detail in Fig. 18.

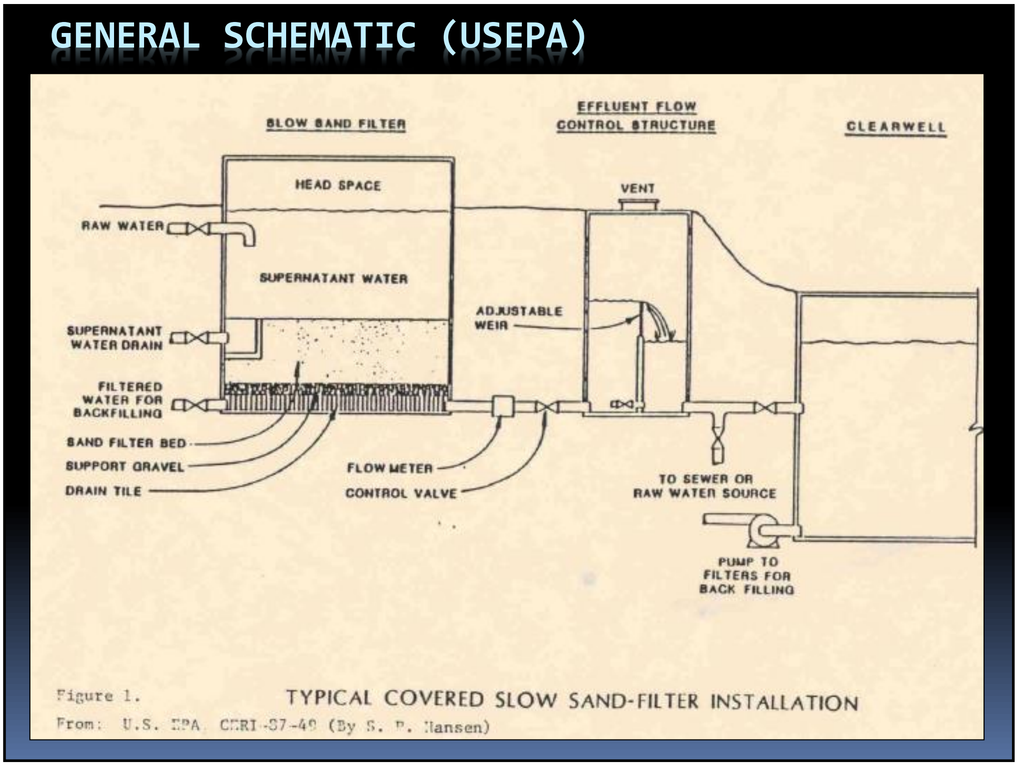
This is a schematic from the 1974 World Health Organization (WHO) “Slow Sand Filtration” design manual (Huisman & Wood, 1974. pg 18).

GENERAL SCHEMATIC (WHO, 1974)

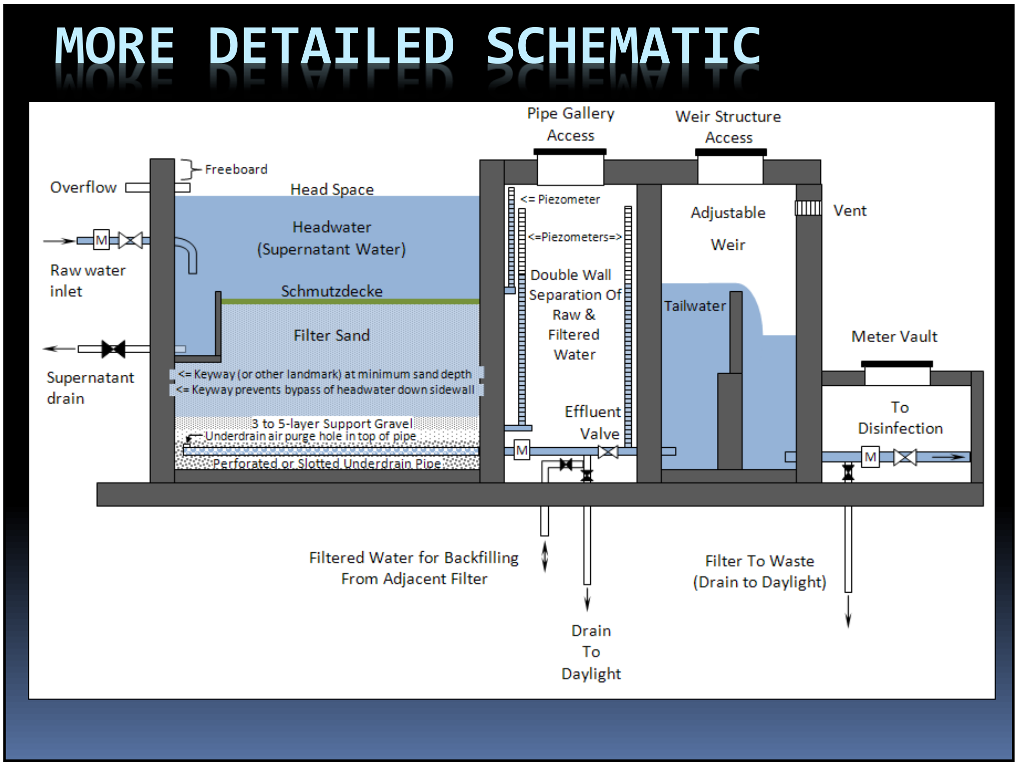
FIG. 18. DIAGRAM OF A SLOW FILTER, SHOWING CONTROL VALVES



This is figure 18 showing more details on the filter controls. Figure 18 is from the 1974 World Health Organization (WHO) “Slow Sand Filtration” design manual (Huisman & Wood, 1974. pg 64).

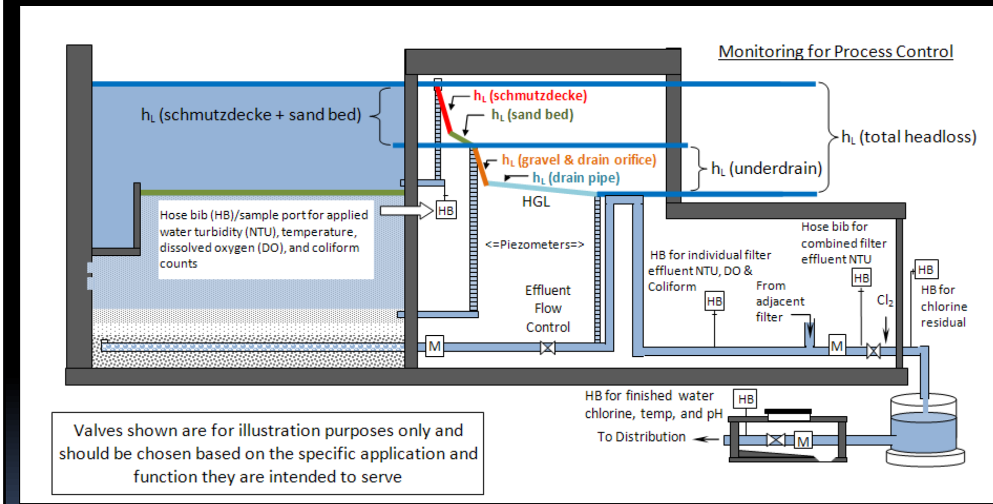


This is another schematic from the USEPA.



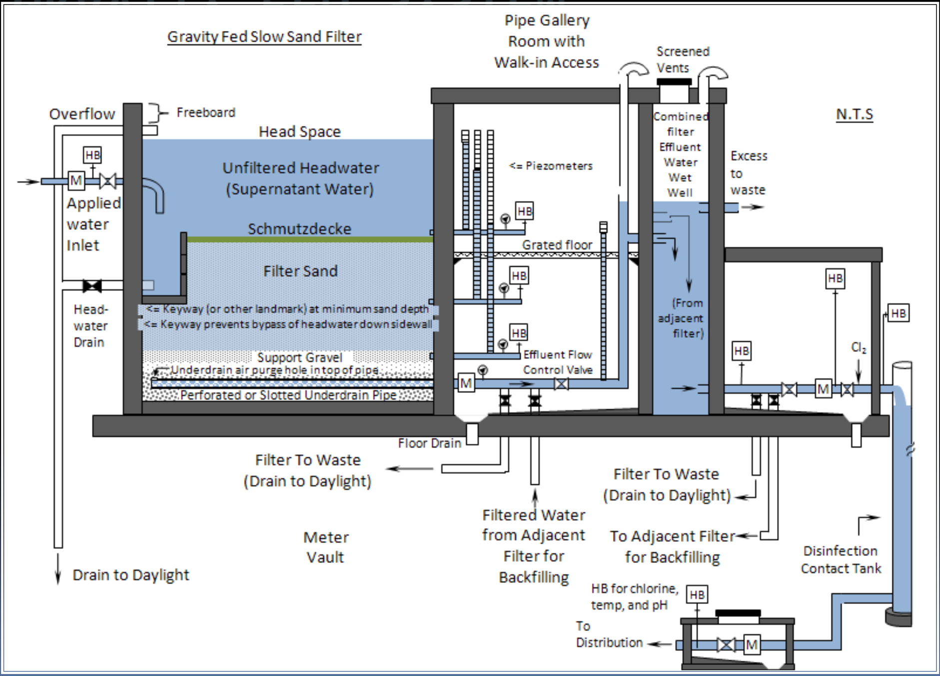
A more detailed schematic is shown here, beginning with the raw water inlet into the filter box. The filter box is equipped with a drain and water for backfilling with filtered water. Supernatant (or headwater) filters through the sand bed and support gravel, out of the under drains through a flow meter and control valve and into a flow control structure. The adjustable weir keeps the sand bed from de-watering when the filtration rate declines towards the end of a filter run. The weir is adjustable to facilitate draining the filter bed during cleaning. Filtered water then flows to the clearwell for disinfection. Piezometers are shown where they can be used to measure headloss across the filter bed as well as the tailwater level.

“GOOSENECK” WEIR

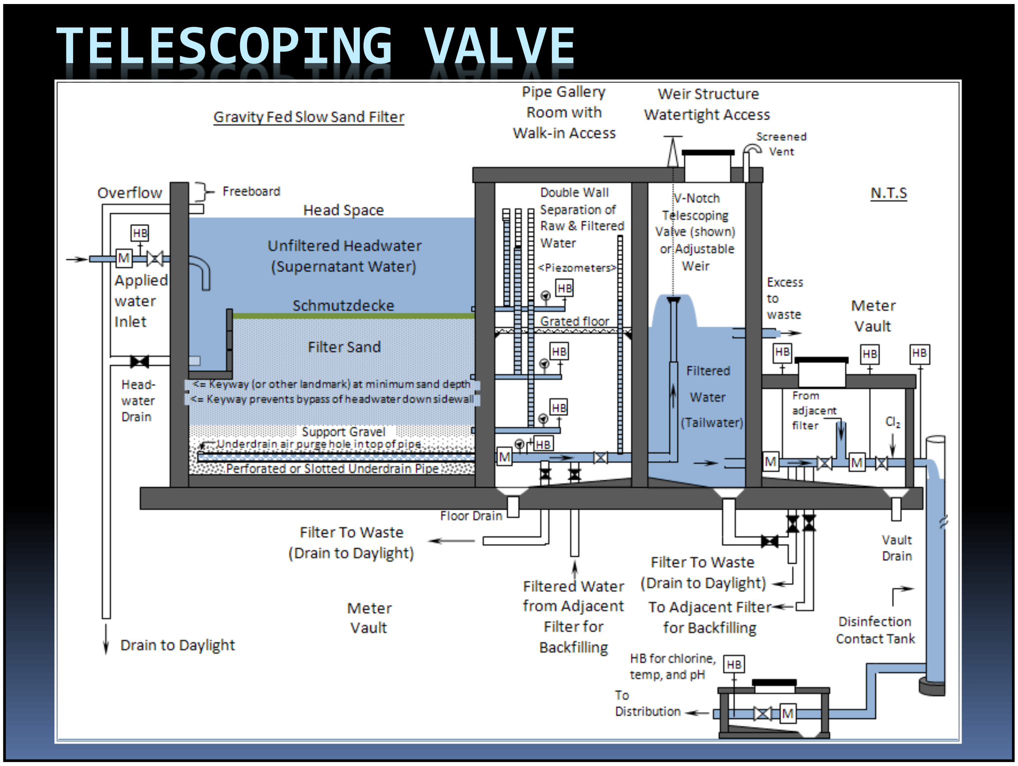


This is an example of a “Gooseneck” style weir construction showing process control monitoring points.

GRAVITY FED SYSTEM



Gravity Fed system



Telescoping Valve

DESIGN - SS VERSUS RAPID RATE

Parameter	Slow Sand Filters	Rapid Rate Filters
Influent Flow	Continuous	Intermittent
Filter Box	☑ - designed to overflow	☑ - not intended to overflow
Filter Media	☑- sand - GAC (rare)	☑ - sand - anthracite - GAC (more common)
Underdrain	☑	☑
"Backwash" mechanisms	☑ - slow filling from bottom of filter – removal of entrained air not media expansion.	☑ - high rate (and low rate) flow designed to suspend & wash the media
Surface Agitator (breaks up media during backwash)		☑

This slide compares slow sand and rapid rate filtration, both utilize similar media (sand), however, there are some important differences. For example, slow sand filters are design to operate continuously, where rapid rate plants are meant for intermittent operation.

DESIGN - SS VERSUS RAPID RATE

Parameter	Slow Sand Filters	Rapid Rate Filters
Filtration Rate	0.03 – 0.1 gpm/ft^2	2-4 gpm/ft^2
Water Above Sand	~4-6 ft	~ 5 ft
Sand Bed Depth	~ 24-48 inches	~ 24-30 inches
Sand Effective Size (d_{10})	0.15 – 0.35 mm	0.45 – 0.55 mm
Retention Time above Sand	15 hrs	9 min
Retention Time in Sand Bed	3.2 hrs	2 min
Cycle Length	1-6 mo	1-4 days
Removal mechanisms	Chemical, physical, and biological (no chemicals)	Chemical and physical (depends on proper coagulation)
Turbidity Removal	Variable even if optimized < 5 NTU by regulation Not indicative of filter performance or pathogen removal. Sub micron particles are not readily removed.	< 0.1 NTU when optimized Good indicator of filter performance and pathogen removal. Coagulation/flocculation removes even sub-micron particles.
Giardia Removal	>3.0 log	>3.0 log
Raw Water Turbidity	<10 NTU	100+ NTU

Filtration rates for rapid rate filters is roughly 40 times that of slow sand filters and the sand effective size is roughly twice that of slow sand media. Retention time above the slow sand bed is measured in hours rather than minutes and the filter run is weeks long rather than days long for rapid rate plants. The removal mechanism for slow sand filters incorporates a biological process without the addition of any coagulation chemicals. Coagulation is critical for effective rapid rate filtration. Due to the coagulation, rapid rate plants are far less sensitive to elevated raw water turbidity. In spite of all these differences, the removal efficiencies for Giardia are the same at 3.0-log and both are capable of producing finished water with very low turbidity.

COMMON DESIGN PITFALLS

Common Design Pitfalls

1. Inappropriate source water quality => inappropriate application
2. Not conducting a pilot study
3. Improperly designed under drains
4. Poorly designed filter piping
5. Inadequate flow control and air binding
6. Insufficient head loss allowed
7. Insufficient sand bed depth
8. Inappropriate filtration rate and variability
9. Poorly specified sand and gravel media (effective size, uniformity, etc.)
10. Poor access to filter bed for cleaning and re-sanding
11. Insufficient sample ports
12. Failure to have the operator involved in design process
13. Failure to provide a good O&M manual with filter cleaning/ripening protocols

Even with the best design, there are a number of variables that can have a big impact on performance. Raw water characteristics like turbidity, color, and colloidal content for example. Other critical variables include sand size and uniformity, flow control and management of air binding, headloss development, sand bed depth, filtration rate and flow variability. Allowing sufficient time to mature once a filter has been newly sanded (usually 4 – 6 weeks) and allowing the filter to ripen once cleaned (24 – 48 hours) are very critical to optimal performance.

DESIGN RECOMMENDATIONS - EXAMPLE

Design parameters	Recommended range of values
Filtration rate **Area per filter bed**	0.15 $m^3/m^2 \cdot h$ (0.1–0.2 $m^3/m^2 \cdot h$) Less than 200 m^2 (in small community water supplies to ease manual filter cleaning)
Number of filter beds	Minimum of two beds
Depth of filter bed	1 m (minmum of 0.7 m of sand depth)
Filter media	Effective size (ES) = 0.15–0.35 mm; uniformity coefficient (UC) = 2-3
Height of supernatant water	0.7–1 m (maximum 1.5 m)
Underdrain system **Standard bricks** **Precast concrete slabs** **Precast concrete blocks with holes on the top** **Porous concrete**	Generally no need for further hydraulic calculations
Perforated pipes (laterals and manifold type)	Maximum velocity in the manifolds and in laterals = .3 m/s Spacing between laterals = 1.5 m Spacing of holes in laterals = 0.15 m Size of holes in laterals =3 mm

Source: Vigneswaran, S. and C. Visvanathan. 1995
http://www.nesc.wvu.edu/ndwc/pdf/OT/TB/TB14_slowsand.pdf

There are a number of design references, such as the one shown here.

DESIGN MANUAL - 1991

"Manual of Design for Slow Sand Filtration" . David Hendricks & American Water Works Association, 1991. ISBN 978-0898675511

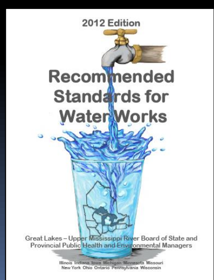
Excellent resource that covers design in great detail

The "Manual of Design for Slow Sand Filtration" covers design in great detail.

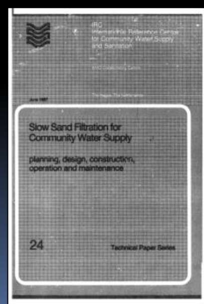
3 OTHER DESIGN REFERENCES

The 3 other main design references include:

1. Recommended Standards for Water Works (a.k.a., "Ten States Standards", 2012);
2. "Slow Sand Filtration for Community Water Supply", International Research Center for Community Water Supply and Sanitation (Visscher et al., 1987)
3. "Slow Sand Filtration", World Health Organization (Huisman & Wood), 1974;



http://10statesstandards.com/



http://www.irc.nl/page/4530

http://www.who.int/water_sanitation_health/publications/ssf/en/index.html

There are, however, 3 main design references that have either stood the test of time, like the manuals on slow sand filtration produced by the World Health Organization and the International Research Center for Community Water Supply and Sanitation or that are commonly referenced by State regulatory agencies, such as the Ten States Standards.

DESIGN CRITERIA – 3 OTHER REFERENCES

The design specifications for these 3 sources are summarized here

Comparison of Design Specifications
(Design Period, Operation, and Filtration Rate, # of Units, and Supernatant Depth)

Reference	WHO Manual (Huisman & Wood, 1974)	IRC Manual (Visscher et al., 1987)	Ten States Standards (2012)
Design Period	7-10 Years	10-15 years	Not Specified
Mode of Operation	Continuous	24 hr/day	Not Specified
Filtration Rate (flow rate ÷ filter area)	0.04 – 0.08 gpm/ft2 (0.1 – 0.2 m/hr)	0.04 – 0.08 gpm/ft2 (0.1 – 0.2 m/hr)	0.03 – 0.1 gpm/ft2
Filter Units (a.k.a., cells)	2 minimum	2 minimum	2 minimum
Supernatant Depth	39 – 59 in, 79 in max (100 – 150 cm, 200 cm max)	27 – 39 in, 60 in max (70 – 100 cm, 150 cm max)	36 – 72 in (91 – 183 cm)

DESIGN CRITERIA – 3 REFERENCES

Comparison of Design Specifications (Minimum Sand Bed Depth)			
Reference	WHO Manual (Huisman & Wood, 1974)	IRC Manual (Visscher et al., 1987)	Ten States Standards (2012)
Minimum Filter Bed Depth*	28 – 35 in (70 – 90 cm)	18 – 35 in (45 – 90 cm)	19 in (48 cm)
*The design should add these minimum sand bed depths to the amount of sand anticipated to be removed during cleanings throughout the design life of the filter (estimates of sand removal can be determined based on cleaning data obtained during pilot testing). Filters designed for harrowing only need to account for minor losses, since sand is not removed due to scraping when using this method of cleaning.			

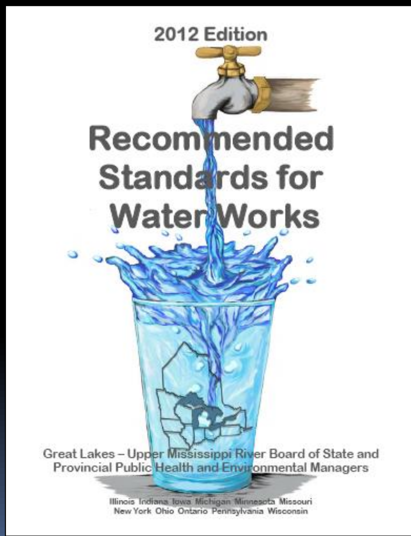
DESIGN CRITERIA – 3 REFERENCES

Comparison of Design Specifications (Filter Sand Effective Size and Uniformity Coefficient)			
Reference	WHO Manual (Huisman & Wood, 1974)	IRC Manual (Visscher et al., 1987)	Ten States Standards (2012)
Filter Sand Effective Size (d_{10})	0.15 – 0.35 mm	0.15 – 0.30 mm	0.15 – 0.30 mm
Uniformity Coefficient (U)	1.5 – 3	< 3 – 5	< 2.5

Other specifications include:

1. Percent of fines passing the #200 sieve < 0.3% by weight
   (can impact post sanding turbidity levels and length of filter to waste time needed to "wash" the fines out)
2. Acid solubility < 5% (can impact sand grain characteristics, effective size, and uniformity coefficient if acid soluble)
3. Apparent specific gravity > 2.55

TEN STATES STANDARDS



Ten States Standards
http://10statesstandards.com/index.html

Member States and Provinces	
Illinois	New York
Indiana	Ohio
Iowa	Ontario
Michigan	Pennsylvania
Minnesota	Wisconsin
Missouri	

Since the Ten States Standards were developed with the participation of many state agencies, are widely recognized, and lay out fairly concise specifications for slow sand filters, I will use this reference to discuss a little about each specification.

TEN STATES STANDARDS

APPLICATION TO BE BASED ON STUDIES

4.3.4 Slow Sand Filters

The use of these filters shall require prior engineering studies to demonstrate the adequacy and suitability of this method of filtration for the specific raw water supply.

PILOT TESTING

Pilot testing

Recommend 1-year pilot study in order to account for seasonal variability of source water variables (required in some cases)

Pilot testing is to determine feasibility (i.e., "will it work when we need it to?"), not just to discover O&M issues.

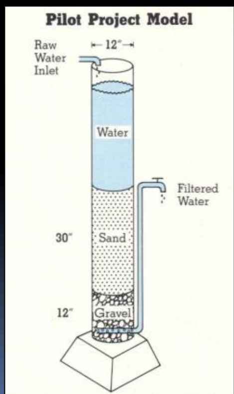
2010. Walla Walla, WA Pilot filters

A pilot study of at least a year should be conducted to determine the suitability of slow sand filtration for the available source water and required system demands. Pilot testing can also uncover unanticipated O&M issues.

PILOT TESTING BENEFITS

Pilot testing

Pilot testing is relatively easy and can be used anytime to test cleaning procedures, model ripening times, or evaluate new media.



<< It can be done on a small scale (1991 - Alsea, OR)

or a very large scale >> (2010 - Walla Walla, WA)

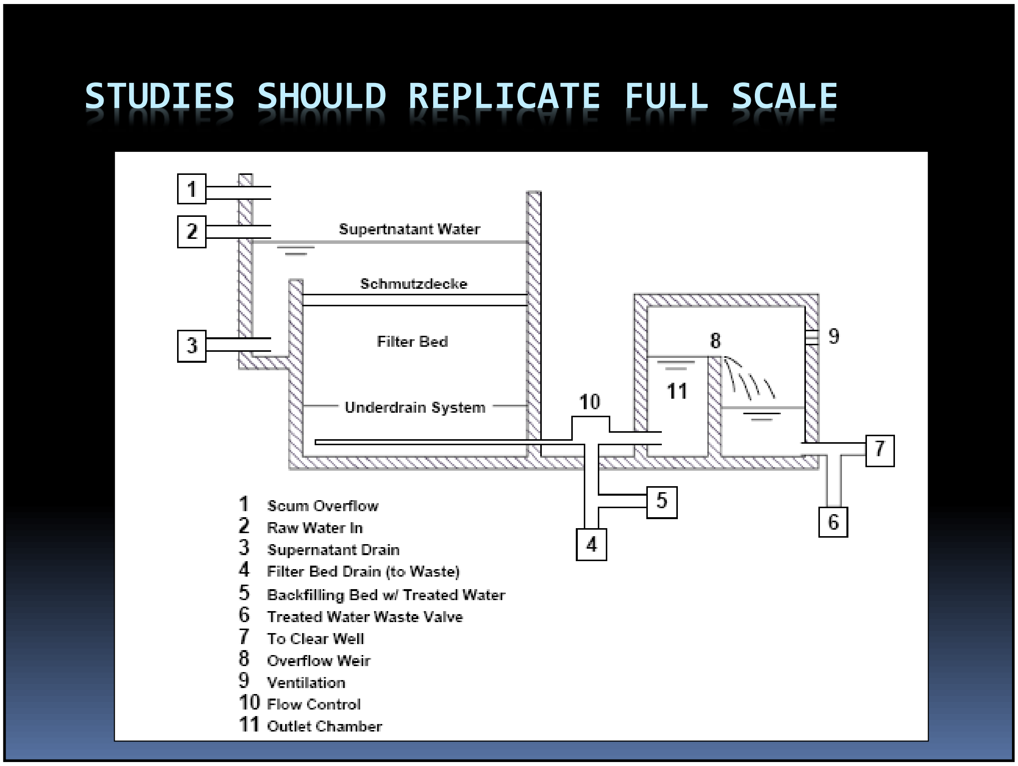
Pilot tests can be small scale like the one on the left with a 12-inch diameter column or large scale like the 4 pilot columns on the right. The one on the left was used to pilot media used in Alsea, Oregon. The pilot study used by Walla Walla Washington in 2010 was used to evaluate media from 3 different sources in 3 of the columns. A 4th column was used to evaluate the effects of a roughing filter.

INFO GAINED BY PILOT TESTING

Pilot testing can yield valuable information such as:

1. The flow to be expected (will the proposed design be enough to meet demands or will more sand bed area be needed?).
2. Cleaning frequency. As sand is removed during cleaning, the frequency of cleaning can yield information about how many years the sand will last before re-sanding is needed.
3. O&M requirements that may change seasonally
4. If algae growth will have an adverse impact
5. Cold temperature effects (may require longer filter-to-waste times after ripening.
6. Ripening time (Use plots of turbidity and coliform)

Pilot testing yields information on what raw water characteristics may adversely impact performance and operation such as algae, cold temperatures, etc.. Pilot test results can be used to evaluate different sand characteristics and determine how much filter area is needed to meet the anticipated demand. It can also be used to estimate operation and maintenance costs associated with cleaning and re-sanding.

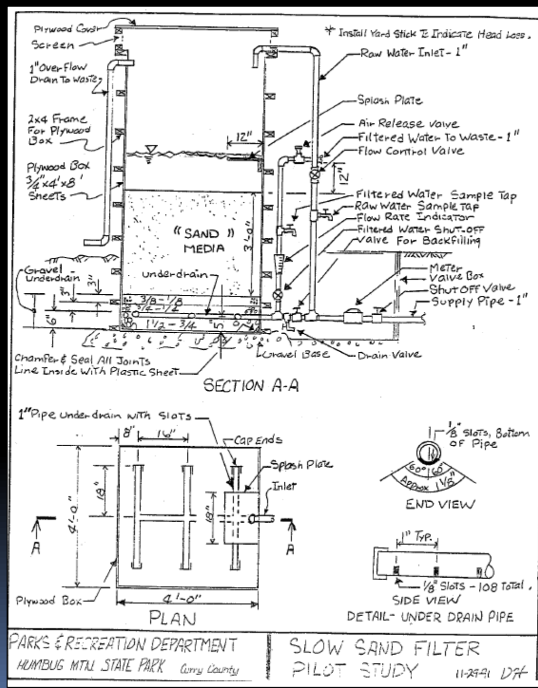


So what are the features of a full scale plant that should be considered in designing pilot filters? Most properly designed slow sand filters have the same basic design elements, with some variations. There is a raw water inlet (#2 in the diagram) and usually some way to remove surface scum (#1) and drain the headwater for cleaning (#3). In a mature filter, there is the schmutzdecke filter skin, filter bed, and underdrain system with some sort of effluent flow control, which is typically either a valve or moveable weir. The underdrain system also functions to drain the filters for cleaning or resanding. During cleaning, the filter bed should not be completely drained, but rather drained just enough to allow the bed to be walked upon or to allow machinery to safely operate during cleaning. In this example, this level is dictated by the design of the outlet chamber (#11) and overflow weir (#8). In other cases, this level is controlled by valves. The water level is maintained in this example by the overflow weir indicated by #8 in the diagram. Once cleaned, there is often the ability to slowly refill the filter bed with filtered water from another filter as shown by #5. This allows air that gets into the filter bed during cleaning to be purged. This “backfilling” continues until the headwater is roughly 1-ft above the filter bed, which protects the bed from scouring that can occur when top filling with raw water commences. There should be the ability to filter to waste for at least 48 hours until ripened (#4).

PILOT FILTER SCHEMATIC

Intent is to replicate full-scale design.

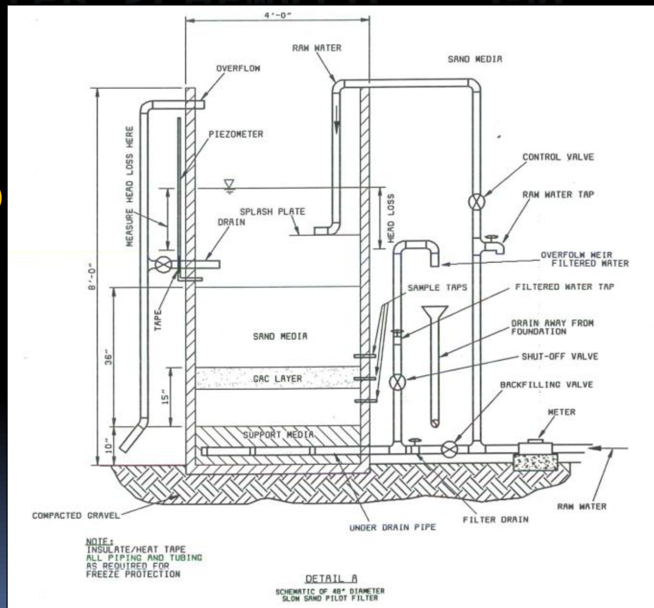
Pilot testing schematics can be simple, but should clearly show key features that can simplify operation and improve data collection.



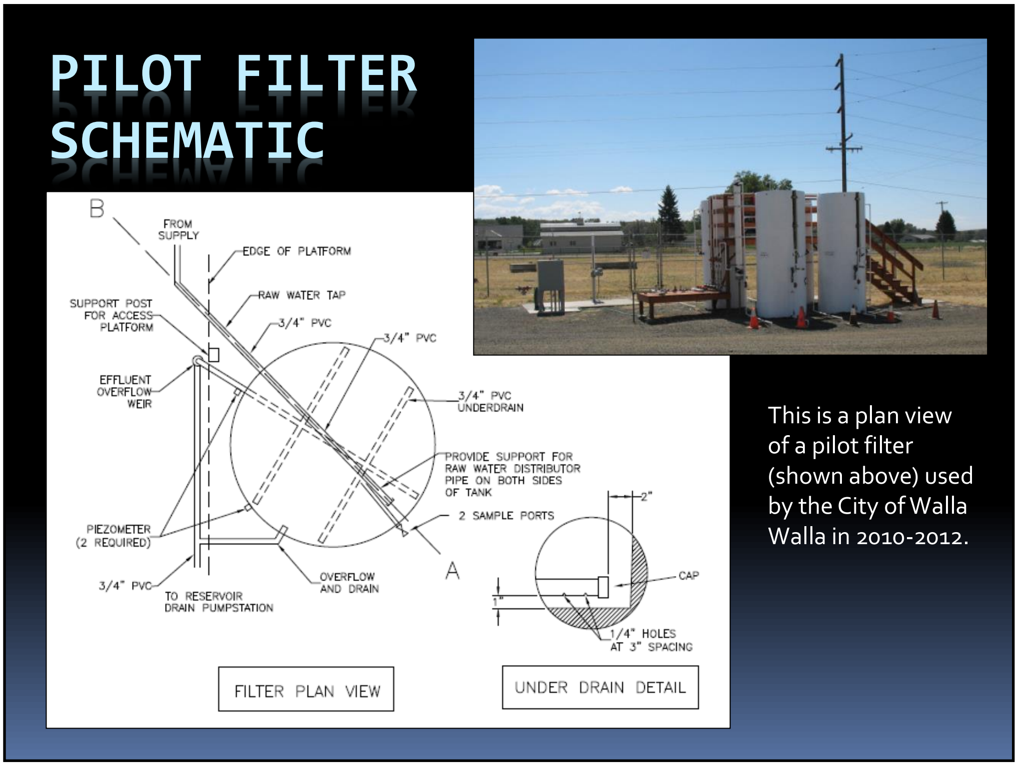
A schematic is an excellent way to ensure that key features of a full-scale plant are incorporated into a pilot filter. Pilot testing schematics can be simple, but should clearly show key features that can simplify operation and improve data collection. This is a schematic of the pilot filter used at Humbug Mountain State Park in Curry County, Oregon.

PILOT FILTER SCHEMATIC - GAC

This design is set up to evaluate a layer of granulated activated carbon (a.k.a. GAC sandwich)



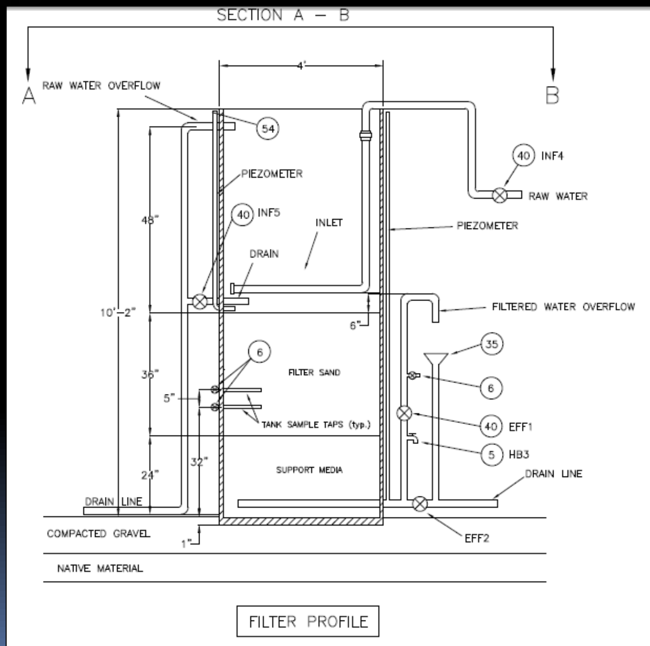
This design incorporates a layer of granular activated carbon for organics removal. This is sometimes called a “GAC sandwich”. These plans are for a pilot filter for the City of Salem.



This is another schematic of a pilot filter used by the City of Walla Walla in 2010-2012.

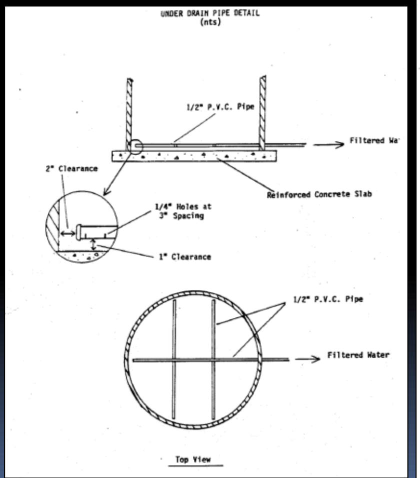
PILOT FILTER SCHEMATIC

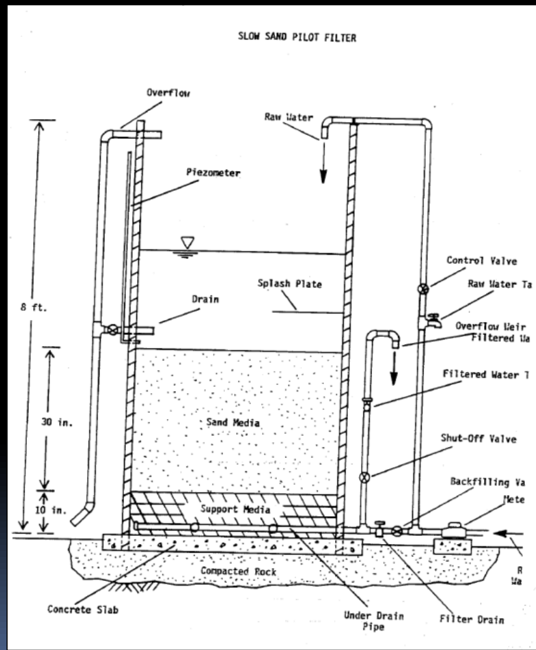
This is a section view of the filter used by the City of Walla Walla, WA.



This is a section view of the filter used by the City of Walla Walla, WA.

PILOT FILTER SCHEMATIC





This is another schematic of a pilot filter.

PILOT FILTER COLUMN

Pilot Filter Material

1. PVC, concrete, fiberglass, etc. (5 gallon buckets have been used). Design some durability into it in order to retain filter for future studies

Pilot Filter Size

1. 8-12 ft high (replicate full scale filter)
2. 12 – 36 inch diameter
3. Diameter dictated by room needed to fit under drains, sample ports, etc. and accommodate cleaning. A joint constructed just above the sand bed can facilitate cleaning in small diameter filters. A lip below the sand surface can help eliminate side-wall effects (short-circuiting) of smaller diameter filters.

Pilot filters can be made out of various materials, but should be made fairly durable so that they can be retained for future studies. Pilot filters should be designed in order to accommodate the entire sand bed, support gravel and under drain system as well as the headwater that would be expected from the full scale installation. Larger diameter filters can help mitigate short-circuiting at the sidewalls, however, a lip built into the filter below the sand bed can help compensate for smaller diameter filters.

PILOT FILTER MEDIA

Pilot Filter Media

1. The media should be the same as that intended to be used in the full scale installation.
2. Multiple, identical filters should be used to evaluate various sources or specifications of sand.
3. Pilot filter media should be delivered and washed as would be done at full scale in order to help estimate the time needed to wash out fines and for the filter to fully mature.
4. The filter bed and support gravel layers should be installed to the same depth anticipated to be used at full scale.

Filter media and support gravels should be supplied, washed, and installed in a similar manner to that anticipated with the full scale installation. This helps to determine the filter wash-out and maturation periods that more closely resembles full-scale conditions. The pilot filter should also be covered or left uncovered like the anticipated full-scale design.

COVERED PILOT FILTERS?

Pilot Filter – to cover or not to cover

1. Pilot filters should be covered if the intended full-scale design includes a cover. If not, it may be advantageous to have the ability to cover the pilot filter in order to observe differences in filter performance.
2. Note that covered filters may not develop a discernable schmutzdecke, rather they may exhibit a layer of darker sand at the surface when maturing.

Tillikum Retreat Center, OR – Covered "Blue Future" filters

The pilot filter should also be covered or left uncovered like the anticipated full-scale design. It may be advantageous to incorporate provisions for covering the pilot filter in order to study differences in filter performance or to evaluate filter covers at a later date. This photograph of excavated media was taken in 2012 at the Camp Tillicum Retreat in Yamhill County, Oregon for a newly installed full-scale filter that was being filtered-to-waste until fully mature.

PILOT FILTER SAMPLE PORTS

Note the sample ports at various locations to evaluate removal mechanisms throughout the filter bed.

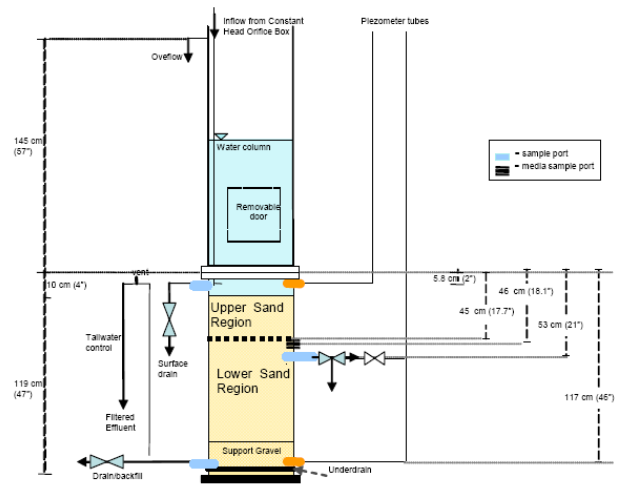


Figure 2. Schematic of Typical Pilot Slow Sand Filter Used in the Winthrop, ME Pilot Study

Here is another example of a pilot filter. Note the sample ports at various column depths. This is not typical, but it demonstrates how a pilot filter can be used to evaluate the removal mechanisms at work throughout the filter bed.

PILOT TEST MONITORING – RAW WATER

Raw Water

Sample location	Parameter	Sample frequency	Laboratory or field analysis needed
Raw water	Turbidity	Daily	Field
	Temperature	Daily	Field
	Apparent color	Weekly	Field
	pH	Weekly	Field
	Alkalinity	Weekly	Field
	Coliform (total and E. coli)	Weekly	Laboratory
	Dissolved oxygen	Weekly	Field
	UV 254 absorbance, TOC and/or THM formation potential	Monthly	Field or laboratory analysis
	Iron and Manganese	Monthly	Laboratory
	Algae identification and enumeration (toxins if indicated)	Quarterly or with algae blooms	Laboratory or field identification. Laboratory or field test strips for toxins.

PILOT TEST MONITORING – FILTER EFFLUENT

Filter Effluent

Sample location	Parameter	Sample frequency	Laboratory or field analysis needed
Filter effluent	Turbidity	Daily	Field
	Temperature	Daily	Field
	Apparent color	Weekly	Field
	pH	Weekly	Field
	Alkalinity	Weekly	Field
	Coliform (total and E. coli)	Weekly	Laboratory
	Dissolved oxygen	Weekly	Field
	UV 254 Absorbance, TOC and/or THM formation potential	Monthly	Field or laboratory analysis
	Iron and Manganese	Monthly	Laboratory
	Algal toxins	If indicated by raw water testing	Laboratory or field test strips for toxins.

PILOT TEST MONITORING - OTHER

Other

Sample location	Parameter	Sample frequency	Laboratory or field analysis needed
Other	Filter head loss	Daily	Field
	Flow rate	Daily and with changes	Field
	Filter run length	Record cumulative days	Field
	Cleaning frequency	Record events and unusual circumstances	Field
	Depth of Sand	Initial amount and amount remaining after each cleaning	Field

PILOT TEST CONCLUSIONS

Key pilot test conclusions that can influence design include…

1. Flow
   - Will it meet system demands?
   - What sand characteristics are most appropriate?
   - How much filter area do I need?
   - Do I need to account for slower flows due to cold temps or should they be covered?
2. Cleaning.
   - What frequency?
   - How much ripening time? Cold water effects?
   - How long can I go without a filter?
   - Will I need multiple smaller filters, rather than fewer large filters due to cleaning and ripening requirements?
   - How long will the filter last & how deep will the bed need to be to make it last given the cleaning required?

PILOT TEST PLAN AND REPORT

Document the pilot test plan and results for future reference

1.2 Study Goals and Testing Objectives

The goals of the pilot study are:

- Determine if SSF is a feasible filtration method to meet present and future regulatory requirements and other water quality goals.
- Determine the operating parameters that optimize treatment capacity and performance.
- Determine costs of the pilot facility that can be used to estimate net present value costs for construction, operation, and maintenance of a full-scale facility.

1.3 Scope and Testing Approach

The scope of the pilot study includes:

- Routine pilot facility operation and water sample collection over a 9-12 month period.
- Analyses of samples.
- Evaluations of the data and a final pilot study report.

CITY OF WALLA WALLA

CITY OF WALLA WALLA

SLOW SAND FILTRATION PILOT STUDY

WORK PLAN

DOH Submittal #10-0604

October 2010

Prepared by:

City of Walla Walla Engineering Division

Darin Christen, E.I.T.

Frank Nicholson, P.E.

TEN STATES STANDARDS
RAW WATER QUALITY

4.3.4.1 Quality of raw water

Slow rate gravity filtration shall be limited to waters having maximum turbidities of 10 units and maximum color of 15 units; such turbidity must not be attributable to colloidal clay. Microscopic examination of the raw water must be made to determine the nature and extent of algae growths and their potential adverse impact on filter operations.

RAW WATER QUALITY

Recommended Limits for Raw Water (Source Water Characteristics)	
Turbidity	< 10 NTU (colloidal clays are not desirable)
True Color	< 5 platinum color units
Coliform Bacteria	< 800 /100 ml (CFU or MPN)
Dissolved Oxygen (DO)	> 6 mg/l (filtered water DO ≥ 3 mg/l)
Total Organic Carbon (TOC)	< 3.0 mg/l (low TOC to prevent DBP issues)
Iron & Manganese	Both < 1 mg/l Each
Algae	< 200,000 cells/L (depends upon type)

Even with the best design, there are a number of variables that can have a big impact on performance. Raw water characteristics like turbidity, color, and colloidal content for example. Other critical variables include sand size and uniformity, flow control and management of air binding, headloss development, sand bed depth, filtration rate and flow variability. Allowing sufficient time to mature once a filter has been newly sanded (usually 4 – 6 weeks) and allowing the filter to ripen once cleaned (24 – 48 hours) are very critical to optimal performance.

TEN STATES STANDARDS
NUMBER OF FILTERS

4.3.4.2 Number

At least two units shall be provided. Where only two units are provided, each shall be capable of meeting the plant design capacity (normally the projected maximum daily demand) at the approved filtration rate. Where more than two filter units are provided, the filters shall be capable of meeting the plant design capacity at the approved filtration rate with one filter removed from service.

NUMBER OF FILTERS

How do you determine a reasonable filter area?

An individual filter should be small enough to allow it to be cleaned in 1 day. Determine the filter size as follows:

Area of 1 filter = (cleaning rate in ft^2/person/hr)
x (no. of people available for cleaning)
x (hours allotted to cleaning)

<u>Example:</u>

Cleaning rate: 1,000 ft^2/5 persons/hr (Cullen and Letterman, 1985)
(1" of sand hand shoveled with hydraulic conveyance)

Number of people: 2 minimum (think safety)
Hours estimated for cleaning: 2.5 hrs (desired)
Area of 1 filter: 1,000 ft^2/5 persons/hr x 2 people x 2.5 hrs
= 1,000 ft^2 => 20 x 50-ft filter

NUMBER OF FILTERS

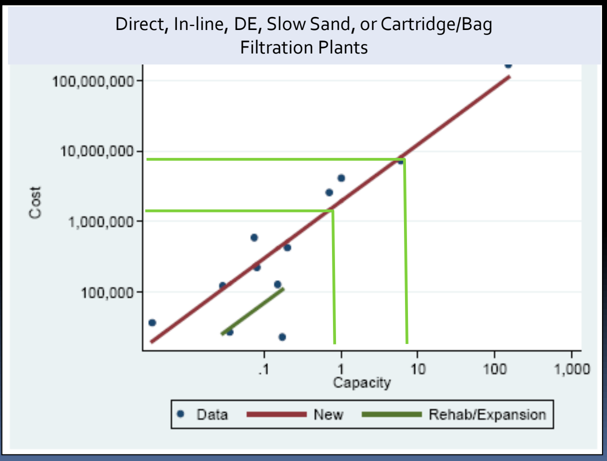
Is there such thing as too small?

The minimum size of a filter depends upon the:

1. Cleaning method and equipment access needs
2. System demands
3. If covers are needed
4. Construction costs

Huisman and Wood (1974) and Sharp et al (1994) indicate a minimum area for one filter of about 1,000 ft^2 (100 m^2). This is due to construction costs being lower per ft^2 with larger filters (economy of scale).

Small modular units are common and can be very cost effective



NUMBER OF FILTERS

How do you determine the number of filters needed?

Equation for number of filters needed: $N = 1 + (Q / (HLR * A))$

Where:

1. HLR = hydraulic loading rate (gpm/ft^2)
2. Q = flow needed to meet demands (gpm)
3. A = The sand bed surface area of one filter bed (ft^2)
4. N = total number of filter beds needed (assumes 1 filter is taken off-line for cleaning and storage can meet peak hour demands)

Example: How many filters are needed, given a peak day demand of 250 gallons per capita per day and a community of 600 people. The peak design filtration rate is 0.1 gpm/ft^2. A minimum rate of 0.05 gpm/ft^2 has been identified through pilot testing for operation during cold conditions and to accommodate filters left in service that may be near the end of their filter run. There is also a desire to limit the size of each filter to 20'x50' in order to facilitate the cleaning:

$$1 + \left[\frac{(250 \text{ gpcpd} \times 600 \text{ people } \times 1 \text{ day}/1440 \text{ minutes})}{(0.05 \text{ gpm/ft}^2 \times (50\text{-ft} \times 20\text{-ft}))}\right] = 3.08 = 3 \text{ filters}$$

The number of filters needed, can be determined using this equation. This equation assumes that the filters are all to be of equal size, only one filter is taken off-line at a time for cleaning, and that peak day demand is the design flow for the plant (i.e., peak hour and fire flow demands can be met by available distribution system storage). Notice, the desire to keep the filter area to a manageable size in order to facilitate cleaning operations and minimize filter down-time. A low rate of 0.05 gpm/sqft is chosen for design as it represents what may be needed should scraping have to occur during colder water temperatures or for filters left in service that may be near the end of their filter run during the remainder of the year (cleaning should generally be scheduled to avoid very cold weather).

NUMBER OF FILTERS

Are more filters better?

Equation for <u>minimum</u> number of filters needed: $N = 1 + (Q / (HLR * A))$

In the previous example, 3 filters were determined to be needed, any 2 of which are capable of meeting 100% of the peak day demand (PDD) to allow for 1 filter being taken out of service for cleaning. This means that each filter is able to meet 50% of the PDD.

3 filters x 50% of PDD = a plant capacity of 150% x PDD

(1 filter off-line leaves 2 filters to meet 100% of PDD)

If 4 smaller filters were constructed, each filter would only need to be capable of meeting ~33% of the peak day demand to allow for 1 being taken out of service.

4 filters x 33% of PDD = a plant capacity of 132% x PDD

(1 filter off-line leaves 3 filters to meet 100% of PDD)

The capital cost involved with fewer large filters should be carefully weighed against the benefits of having a higher number of smaller filters (smaller overall plant capacity, more operational flexibility, shorter time cleaning each filter, although more filters to construct and maintain)

SYSTEM DEMANDS

System demands and operation to consider…

1. 20-year planning horizon
2. Average day demands (ADD) – Design Goal
3. Peak day demands (PDD) – Design Goal
4. Peak hour demands (use storage)
5. Available storage (3 days ADD recommended)
6. Account for cleaning/ripening (min 2 filter beds) – ability to meet PDD with largest filter off-line.
7. Keep filtration rates below 0.1 gpm/ft^2
8. Avoid rapid flow changes (strive for weekly or monthly changes)
9. Plan for constant flow through filter (constant supply of nutrients for biological health)

Tank for City of Astoria, OR

For planning purposes, system demands should be estimated for a minimum of 20 years into the future. Filters should be designed with enough surface area to meet peak day demands with the largest filter out of service without making drastic flow changes. Even though installations may be small, a minimum of two filters should be installed to allow for taking one filter off-line for several days during cleaning and ripening. The filter area should be large enough to meet these demands, while maintaining a filtration rate between 0.1 and 0.16 gpm/ft2. Should storage not be enough to meet peak hour demands, then the filter area should be expanded to meet these demands as well. Typically this is not needed when storage is capable of meeting 3 or more days of average demand.

TEN STATES STANDARDS
STRUCTURAL DETAILS & HYDRAULICS

4.3.4.3 Structural details and hydraulics

Slow rate gravity filters shall be so designed as to provide:

a. a cover,
b. headroom to permit normal movement by operating personnel for scraping and sand removal operations,
c. adequate access hatches and access ports for handling of sand and for ventilation,
d. an overflow at the maximum filter water level, and
e. protection from freezing.

FILTER BOX

Filter boxes and earthen cells

1. Water tight. Filter boxes should be watertight, not merely to prevent loss of treatment water, but to exclude ingress of groundwater, which might contaminate the treated effluent. If possible, ensure the floor is above the highest water table.

2. Allows for cleaning and re-sanding efforts.

3. Insulated from freezing (below ground, covered, or fully enclosed) .

4. Covered as needed to prevent algae blooms and exclude falling leaf litter.

5. Freeboard of 4 – 12” (10 – 30 cm) above overflow level.

FILTER WALLS - VERTICAL

Vertical Walls

Short circuiting of the filter-bed along vertical walls can be mitigated by using a keyway (6x8 cm), rough sloped walls, or a batter.

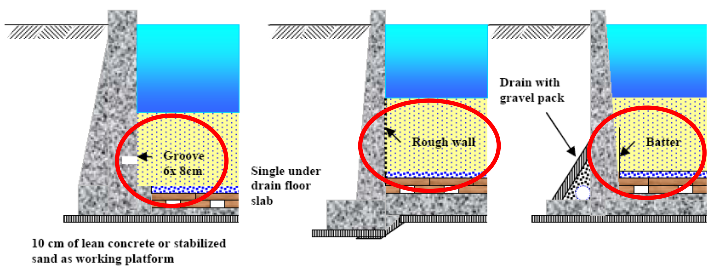


Figure 12: Method of preventing the short circuiting of the filter bed along the vertical wall (WHO)

This diagram shows three mechanisms to prevent short circuiting along the interface with vertical side walls and the filter sand bed. The WHO manual indicates that the most effective precaution is to give the walls a slight outward batter, so as to obtain the advantages of sloping walls and to use grooved or roughened surfaces.

FILTER WALLS - VERTICAL

City of Sumpter (Baker Co)

3 cells
360,000 gpd
completed
In the spring of 2003

This photograph shows how a circular basin can be divided to provide more cells, making cleaning easier since only 1/3 of the basin needs to be cleaned at a time.

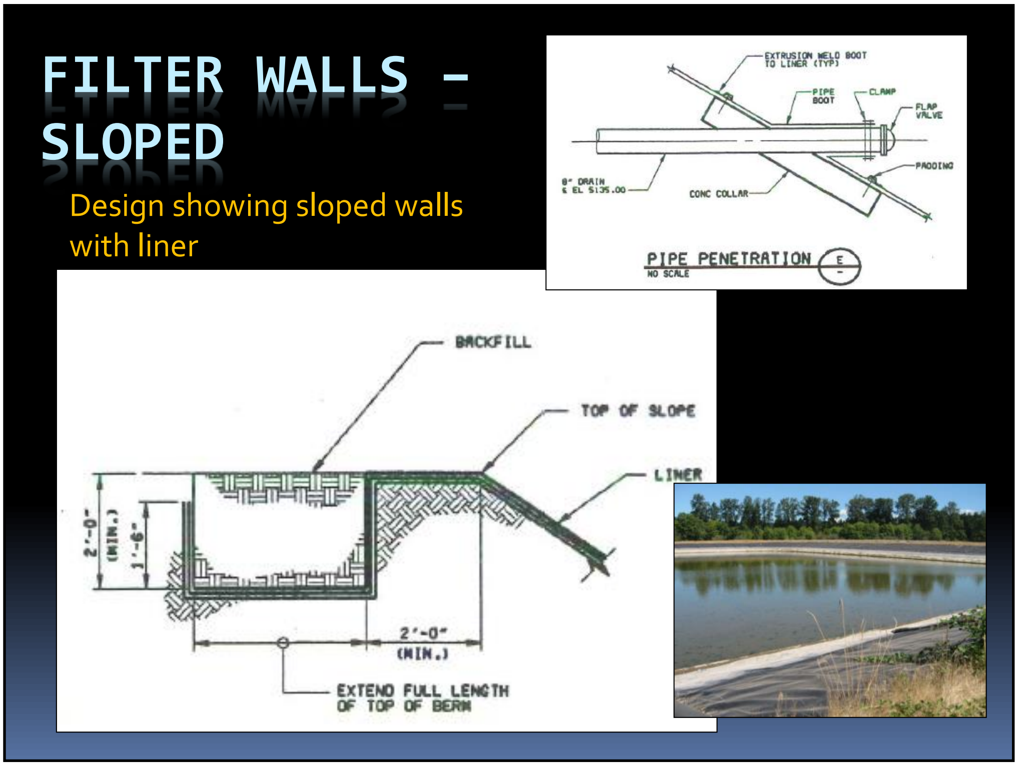
FILTER WALLS - VERTICAL

Vertical Walls

Ramps allow to get equipment and new sand in and old sand out.

Ramps allow to get equipment and new sand in and old sand out of vertical walled filter boxes. This photograph shows the two of the filters for Falls City, OR.

Removable stop logs allow for cleaning filters used by the City of Banks, OR.



These schematics show the construction of an in-ground filter with a liner and sealed pipe penetrations.

COVERED FILTERS

If covered and/or housed in a filter building, make sure ample room exists to enable cleaning.

2012. Camp Yamhill in Yamhill County Oregon.

COVERED FILTERS

Protection from freezing

Even if the filters are enclosed, like these "Blue Future" filters, they may not provide enough protection from freezing temperatures. These filters were eventually enclosed in a building.

2009. Jewell School District #8, OR. "Blue Future" covered filter (left) and raw water control tank (right)

This photo shows a covered "Blue Future" filter installed at the Jewell School District #8 in 2009. The green tank on the left is the filter, the taller green tank on the right is the raw water control tank, and the small grey tank in the middle is the effluent control tank. These filters are designed to be harrowed rather than scraped. Harrowing will be discussed a little later.

COVERED FILTERS

Wickiup Water District (Clatsop Co)

Two 80’x30’ cells
120 gpm (0.025 gpm/sf)
Framework allows for shade cloth to be used during the summer

COVERED FILTERS

Thames Water (London England)

Positive air pressure support a plastic film cover at Thames Water.

Plate 2.2 - Internal view of a slow sand filter covered by plastic film supported by positive air-pressure at Walton, Thames Water

SLOW SAND DESIGN
UNCOVERED VS. COVERED

Note the difference in biomass development following scraping (Campos et. al, 2002/2006) – this should be considered in sizing system

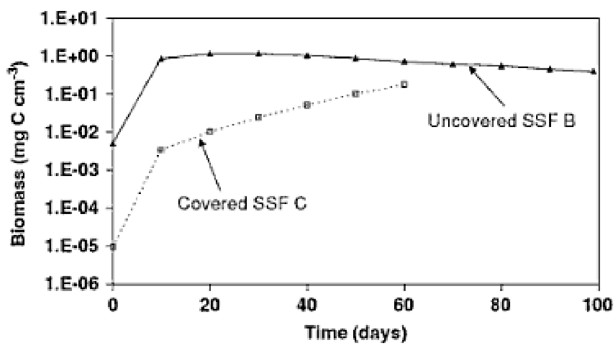


Figure 3 Development of biomass in (a) uncovered SSF B, and (b) covered SSF C (Note: Biomass concentration plotted on logarithmic scale).

Note the difference in biomass development following scraping (Campos et. al, 2002/2006). This information can be obtained during a pilot study.

SLOW SAND DESIGN
UNCOVERED VS. COVERED FILTERS

Parameter	Uncovered	Covered
Temperature	More exposed to lower temperatures which can adversely impact biological activity and increase filter ripening times.	Less susceptible to temperature effects
Algae	Algal growth/blooms in the headwaters can increase clogging	Not as susceptible to localized algae blooms.
Biomass Development	Filter has a higher biomass and develops a more noticeable schmutzdecke.	Overall biomass levels are lower and schmutzdecke formation may appear non-existent or present as an easily suspended, inert, black carbonaceous deposit of about 1 mm in thickness. Biomass is significantly correlated to bacteria counts.
Removal Efficiency	Equivalent	May be adversely impacted by lack of schmutzdecke layer

This table shows some of the differences experienced in filters with and without a cover. Although there are some important differences, deciding to cover the filters may be dictated by site constraints (space, temperatures, etc.) and the amount of filter area needed (is it practical?).

TEN STATES STANDARDS
FILTRATION RATE

4.3.4.4 Rates of filtration

The permissible rates of filtration shall be determined by the quality of the raw water and shall be on the basis of experimental data derived from the water to be treated. The nominal rate may be 45 to 150 gallons per day per square foot of sand area (1.8 - 6.1 m/day), with somewhat higher rates acceptable when demonstrated to the satisfaction of the approving authority.

45 – 150 gpd/ft^2
(0.031 – 0.10 gpm/ft^2)

FILTRATION RATE
(HYDRAULIC LOADING RATE)

Equation for Determine HLR: HLR = Q / (A * (N-1))

Where:

1. HLR = hydraulic loading rate (gpm/ft^2)
2. Q = flow needed to meet demands (gpm)
3. A = The sand bed surface area of one filter bed (ft^2)
4. N = total number of filter beds needed $\geq$ 2 ("N-1" is the total number of filters with 1 filter taken out of service for cleaning)

Example: Given a peak day demand of 250 gallons per capita per day and a community of 600 people served by two 50'x20' filters:

$$\frac{250 \text{ gpcpd} \times 600 \text{ people}}{(1{,}000 \text{ ft}^2/\text{filter} \times (2 \text{ filters} - 1 \text{ filter})} = 150 \text{ gpd/ft}^2 \ (0.1 \text{ gpm/ft}^2)$$

This equation is used to determine the filtration rate (or hydraulic loading rate) of slow sand filters.

FILTRATION RATE

Maximum
≤ 0.1 gpm/ft^2

Rate may need to be ≤ 0.05 gpm/ft^2 when water temp <5 °C

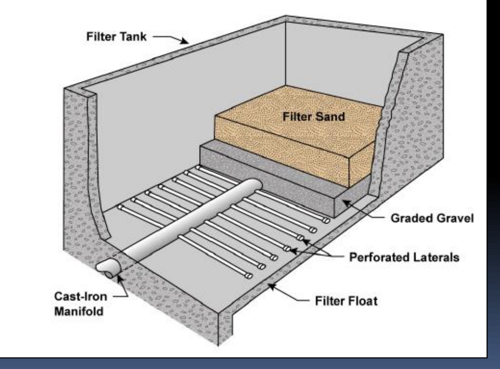
Minimum
≥ 0.02 gpm/ft^2 to keep biota viable

TEN STATES STANDARDS
UNDERDRAINS

4.3.4.5 underdrains

Each filter unit shall be equipped with a main drain and an adequate number of lateral underdrains to collect the filtered water.

The underdrains shall be placed as close to the floor as possible and spaced so that the maximum velocity of the water flow in the underdrain will not exceed 0.75 feet per second.



The maximum spacing of laterals shall not exceed 3 feet if pipe laterals are used.

UNDERDRAINS

underdrains are typically made using perforated pipe laterals (PVC, NSF-61) due to minimal head loss.

For larger installations, laterals are typically 4-8″ in diameter, while main drains are 12-18″ in diameter.

underdrains are typically constructed of PVC (NSF-61), which has minimal head loss.

UNDERDRAIN CONFIGURATIONS

Common configurations include laterals that connect to a main drain system. Smaller filters will often have only 1 main drain like the one shown on the right.

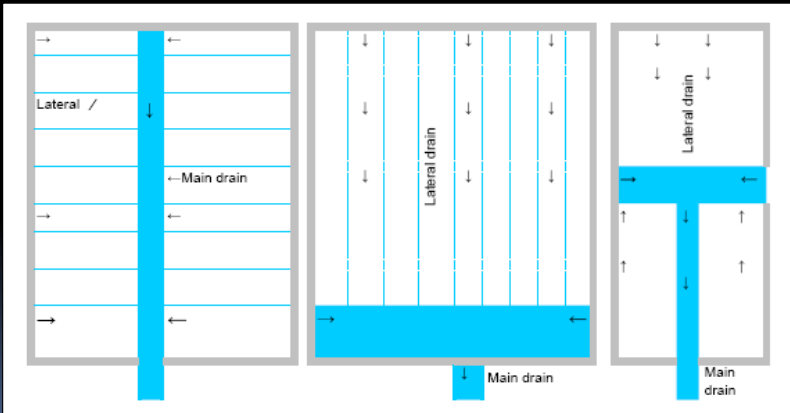
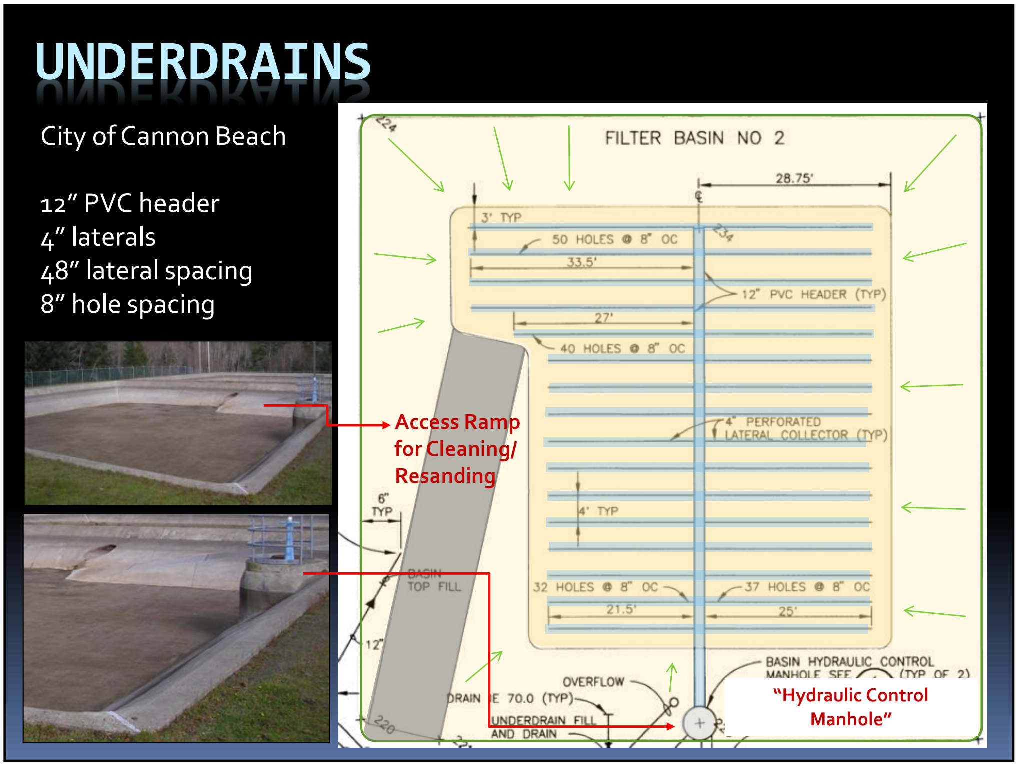


Figure 10: Common arrangements for the main drain of a slow sand filter

Common configurations include laterals that connect to a main drain system. Smaller filters will often have only 1 main drain like the one shown on the right.

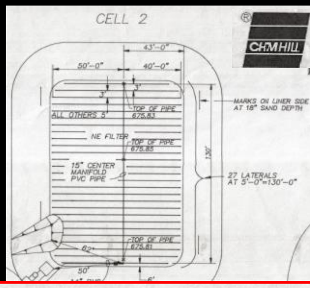


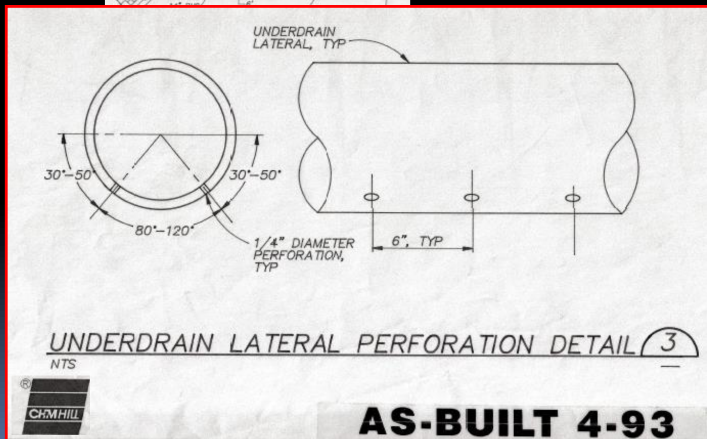
Here is a plan view of the underdrains for the City of Cannon Beach, Oregon.

UNDERDRAINS

City of Astoria (5 MGD)

Filter Cell #2
1993 filter rebuild
15” PVC manifold
14” PVC header
6” laterals
60” lateral spacing
6” hole spacing
¼” drain holes

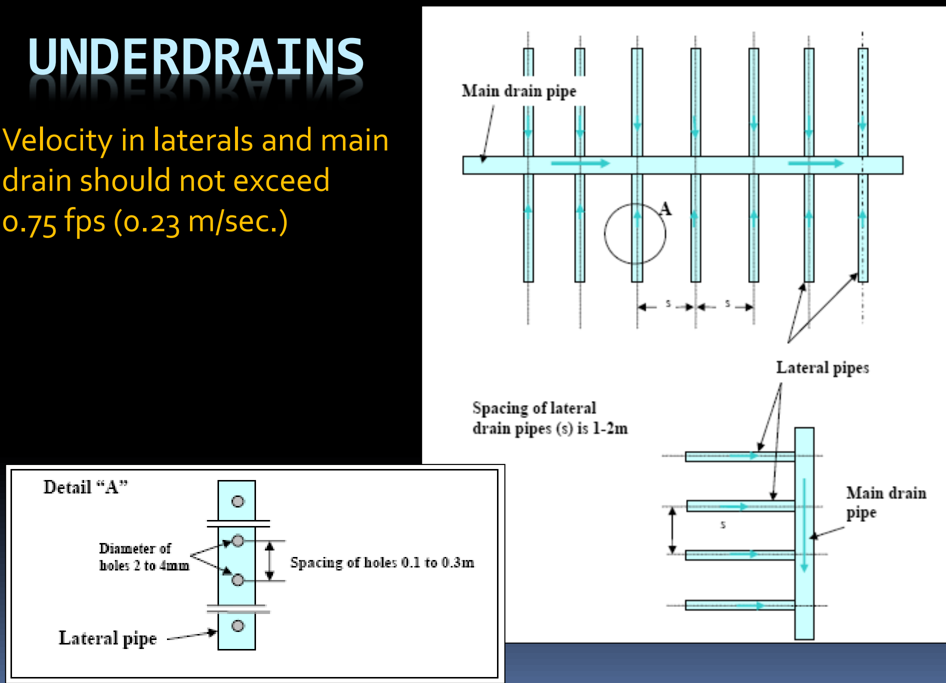




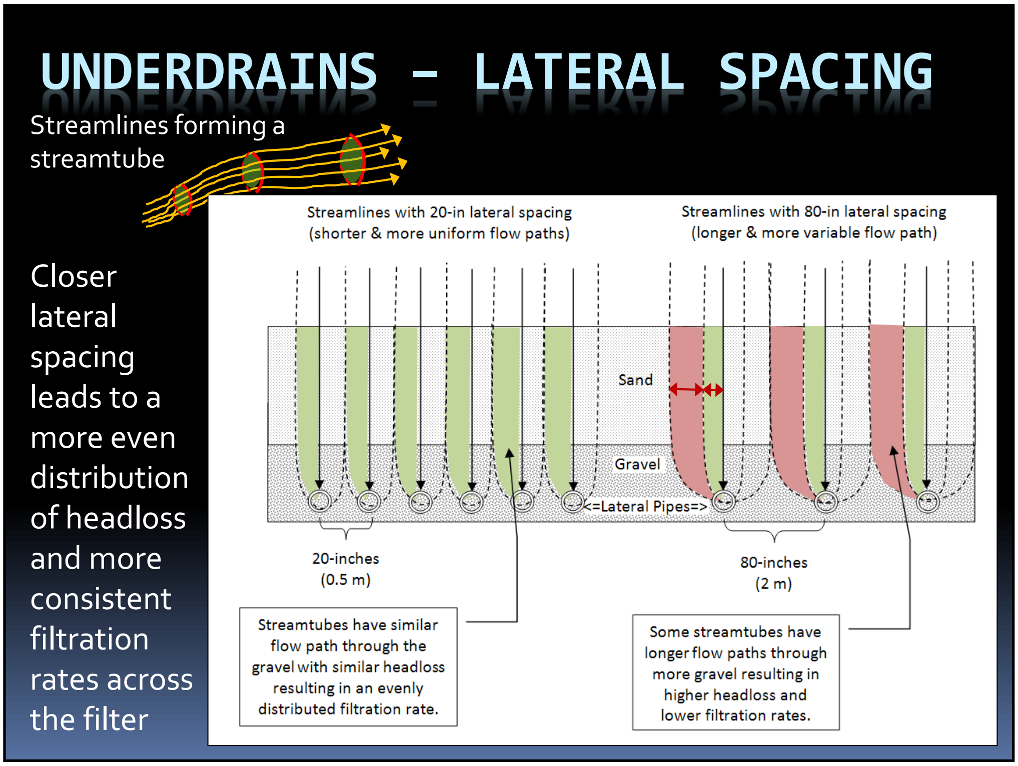
This shows a detail of the lateral pipe perforations of the underdrain system for filter cell #2 for the City of Astoria, Oregon.

UNDERDRAINS

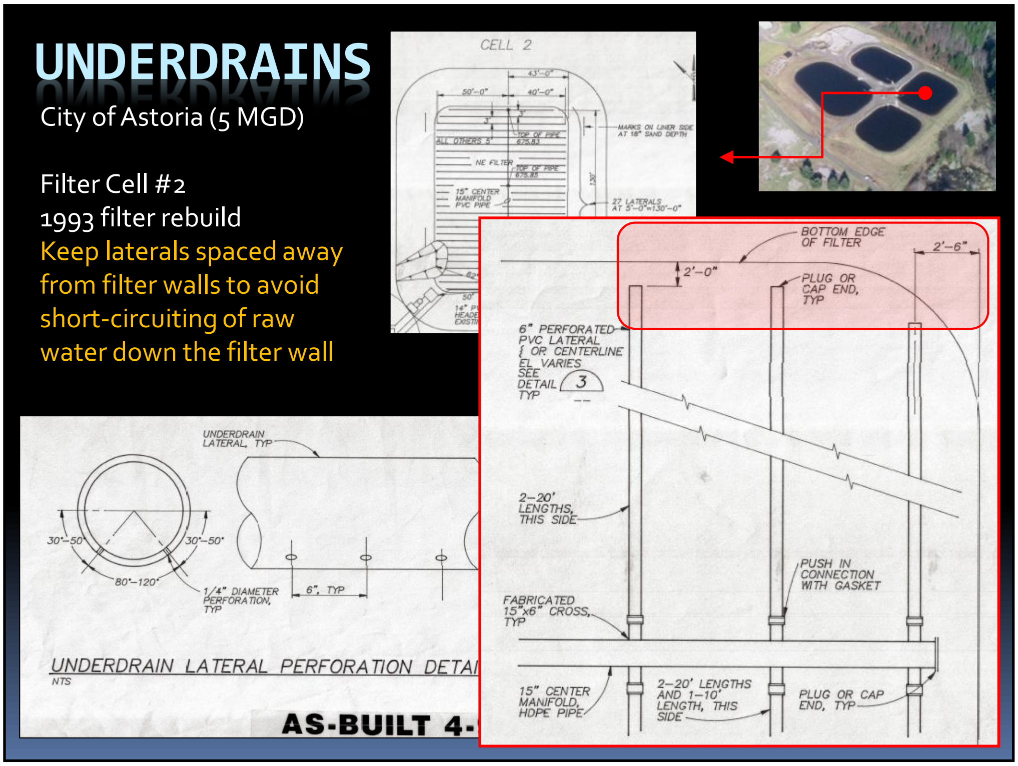
Velocity in laterals and main drain should not exceed 0.75 fps (0.23 m/sec.)



Velocity in the laterals and main should not exceed 0.75 fps (0.23 m/sec). This diagram shows the configuration of the main drain pipe and laterals. Note the spacing of laterals at 3 – 5 feet apart (1-2 meters). Drain holes should be 5/64" – 5/32" in diameter (2-4 mm) and spaced every 4 to 12 inches apart (0.1 – 0.3 meters).

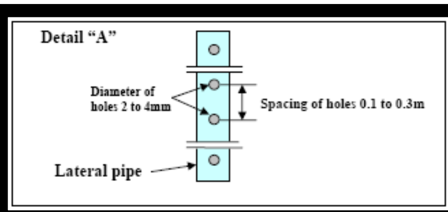


This diagram illustrates how the spacing of laterals can impact the flow of water through the underdrains (indicated by streamlines) and the resulting increase in headloss and decrease in filtration rate with larger lateral spacing.



Keep laterals spaced away from filter walls to help prevent sidewall effects where unfiltered water can slip past the filter media down the sidewall.

UNDERDRAINS



Underdrain Design Parameters	Recommended Specification
Maximum Velocity in Laterals[1]	0.75 fps (0.23 m/sec)
Maximum Velocity in Main Drain[1]	0.75 fps (0.23 m/sec)
Spacing of lateral drain pipes[1]	36 inches (91.4 cm)
Spacing of bottom lateral drain holes[2]	4 – 12 inches (0.1 – 0.3 m) (include air release holes @ ends on top of laterals)
Diameter of drain holes[2]	5/64" – 5/32" (2-4 mm) (needs to be determined through hydraulic calculations)
Material	Non-Corrosive and meeting NSF-61 (e.g., PVC)

[1] Source: 2012 Edition of the Recommended Standards for Water Works (Ten States Standards). Visscher et., al. (see footnote 2) recommended 1.64 fps (0.5 m/sec).
[2]Source: Visscher, J.T., R. Paramasivam, A. Raman, and H.A. Heijnen. 1987. *Slow Sand Filtration for Community Water Supply, Planning, Design, Construction, Operation and Maintenance*. Technical Paper No. 24, The Hague, Netherlands: International Reference Center for Community Water Supply and Sanitation.

Design recommendations from the IRC manual are included here. One addition is the provisions for air release holes at the ends on top of the laterals to purge air pockets in the laterals upon initial filling.

TEN STATES STANDARDS

FILTER MEDIA

4.3.4.6 Filter material

a. Filter sand shall be placed on graded gravel layers for a minimum depth of 30 inches.

b. The effective size shall be between 0.15 mm and 0.30 mm. Larger sizes may be considered by the reviewing authority; a pilot study may be required.

c. The uniformity coefficient shall not exceed 2.5.

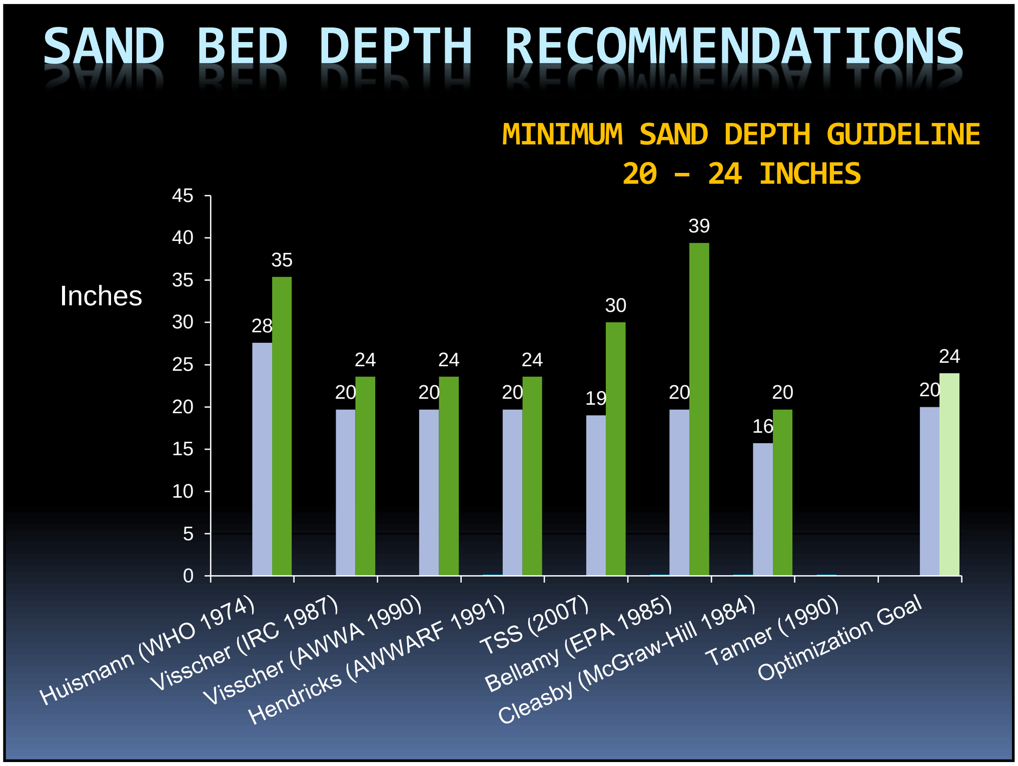
d. The sand shall be cleaned and washed free from foreign matter.

e. The sand shall be rebedded when scraping has reduced the bed depth to no less than 19 inches. Where sand is to be reused in order to provide biological seeding and shortening of the ripening process, rebedding shall utilize a "throw over" technique whereby new sand is placed on the support gravel and existing sand is replaced on top of the new sand.

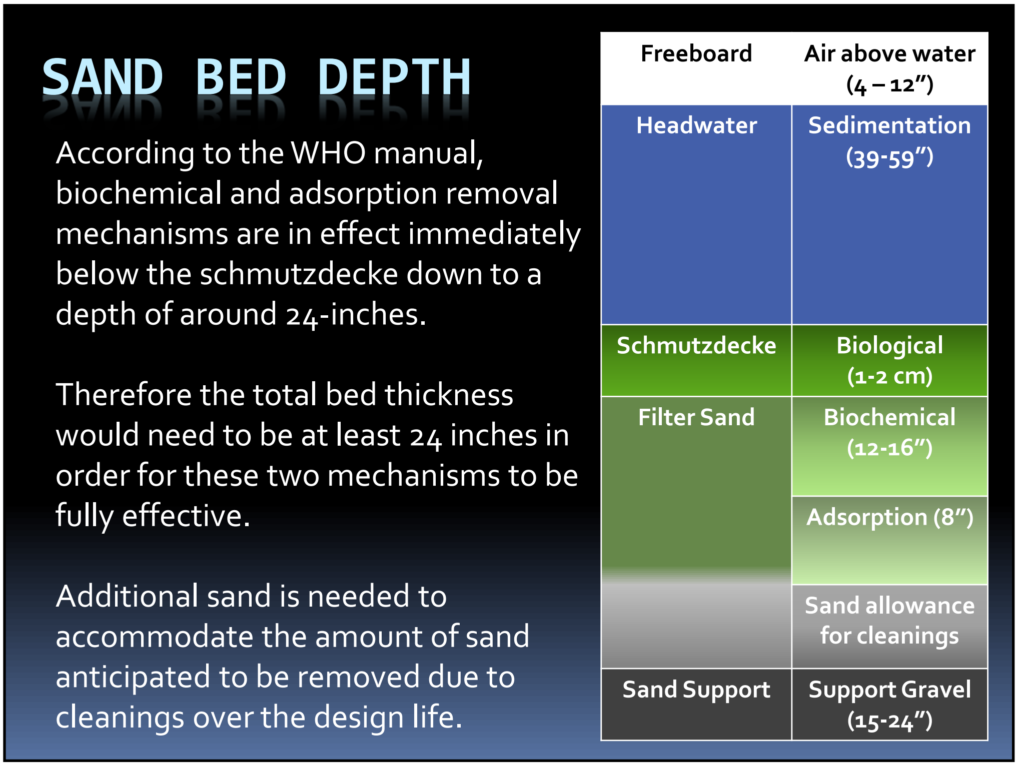
FILTER MEDIA

Plan the work and provide an adequate budget so recommended media specifications and placement practices are able to be followed – it will pay off in the long run!

Plan the work and provide an adequate budget for media – it will pay off in the long run!



Various sources all fall within 16 – 35 inches, however, most recognize 20 – 24 inches as a minimum level the sand bed ought to be allowed to operate with.



As covered in the discussion on removal mechanisms, a certain amount of sand ranging from 20 – 24” is needed to ensure that the removal mechanisms remain available for the entire life of the filter bed. In order to ensure this, an added sand allowance is needed to account for successive cleanings over the life of the filter.

SAND BED DEPTH - FORMULA

Formula for determining depth of sand:

$$D_i = [Y (R * f_{scraping})] + D_f$$

Re-arrange to find design life: $Y = (D_i – D_f) / (R * f_{scraping})$

Where:

Y = years of operation before sand bed needs rebuilding

D_i = initial sand bed depth (inches)

D_f = final sand bed depth before rebuilding (inches)

R = sand depth removal per scraping (inches/scraping)

$f_{scraping}$ = frequency of scraping (scrapings/year)

This is used to determine the additional sand allowance needed to account for successive cleanings over the life of a filter.

SAND BED DEPTH - EXAMPLE

Example: $D_i = [Y (R * f_{scraping})] + D_f$

Given:

1. D_i = initial sand bed depth (inches)
2. D_f = 24 inches
3. $f_{scraping}$ = 6 cleanings per year
4. R = Removal of 1.3 cm (1/2") of sand per cleaning
5. Y = 7-year design life (before re-sanding is needed)

Di = 7 yrs * (0.5 in/scraping * 6 scrapings/year)] + 24 in
= 45 inches

Therefore, an additional 21 inches (53 cm) of sand is needed to allow for scraping over 7 years.

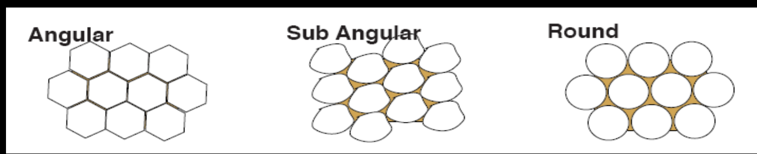
This example shows how one would use the same formula to determine the additional sand allowance needed to account for successive cleanings over the life of a filter.

FILTER MEDIA - SILICA

Silica sand

- Durable
- Inexpensive
- Readily available

- The most important feature is the pore space in the media.



- Removal mechanisms occur in the pores where suspended solids are trapped, microorganisms grow, and air and water flow.
- Using media with an appropriate effective size and uniformity ensures an optimal pore space.

Media selection is critical to proper operation and should be primarily silica sand, due to it’s durability and availability.

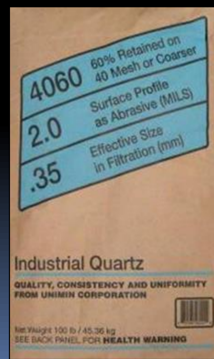
FILTER MEDIA – GRAIN SIZE

There are many different "grades" of sand available

QUIKRETE® Filter Sand has a predominant size range as follows:

US Sieve Size	20-40
Particle size	(0.85-0.425 mm)

"Sand" ranges from 0.0625 mm (#230 sieve) – 2.0 mm (#10 sieve)



FILTER MEDIA - SIEVE SIZES

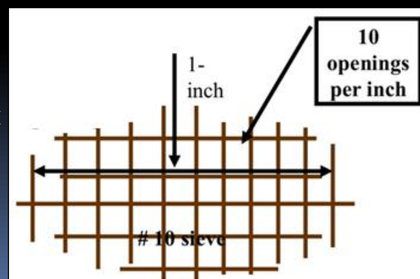
Sieves larger than the #4 sieve are designated by the size of the openings in the sieve.

Sieve Number	Opening (mm)
4	4.750
6	3.350
8	2.360
10	2.000
16	1.180
20	0.850
30	0.600
40	0.425
50	0.300
60	0.250
80	0.180
100	0.150
140	0.106
170	0.088
200	0.075
270	0.053

Smaller sieves are numbered according to the number of openings per inch.

Example: A #10 sieve is made with 0.0237" thick wire. What is the opening size?

9 wires/in x 0.0237"/wire = 0.213"
1" – 0.213" = 0.787"
Opening width = 0.787"/10 openings = 0.0787"
0.0787" = 2.0 mm

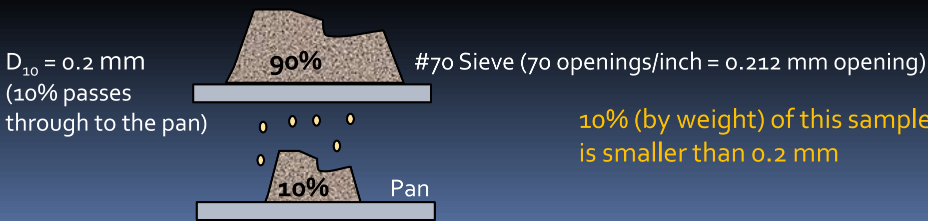


Sieves are numbered in one of two ways. Sieves larger than the #4 sieve are designated by the size of the openings in the sieve. Smaller sieves are numbered according to the number of openings per inch. The thickness of wire must be accounted for in determining the opening. For example, a #10 sieve has 10 openings per inch. The openings are only 0.0787 inches (2.0 mm) because the sieve is made using 0.0237" thick wire. Since there are 9 wires within an inch to make up 10 openings per inch, the wire accounts for the remaining 0.213" inches.

FILTER MEDIA - EFFECTIVE SIZE (D_{10})

Effective Size (D_{10})
Range should be 0.2 mm to 0.35 mm

- The effective size gives a good indication of the permeability characteristics of sand.
- D_{10} is the size of grain such that 10% by weight of the total sample is smaller. (i.e., 10% of the sand, by weight, is finer than a given grain size).



One critical sand specification is the effective size. The effective size (or diameter) is typically expressed as D_{10} and indicates the grain diameter in millimeters at which 10% of the total grains of a given sample are smaller and 90% of the total grains are larger, based on weight. The effective size for slow sand media should be between 0.2 mm to 0.35 mm. Ten States Standards recommends a range of 0.15 – 0.35 mm, but the 0.15 mm specification often only restricts production without any added benefit.

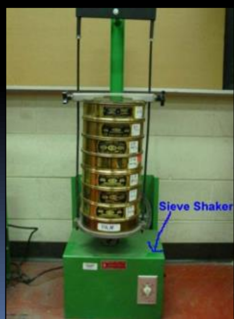
FILTER – DETERMINING D_{10}

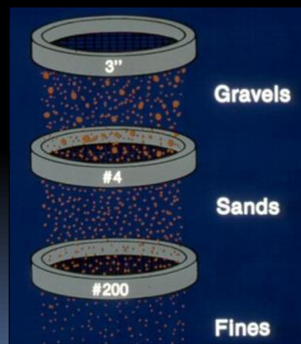
Effective Size (D_{10})
Range should be 0.2 mm to 0.35 mm

A sieve analysis is done to determine D_{10} by:

1. Passing a known amount of media through a series of progressively smaller sieve sizes; and

2. Weighing the amount of media retained on each sieve.





The effective size is determined by doing a sieve analysis. So for example, you take a measured quantity of sand and weigh it. Then you sift it through a series of sieves with progressively smaller screens and weigh the portion of sand retained on each sieve.

FILTER MEDIA - DETERMINING D_{10}

Percentage retained on any sieve:

= 100% x (weight of soil retained / total soil weight)

Cumulative percentage retained on any sieve:

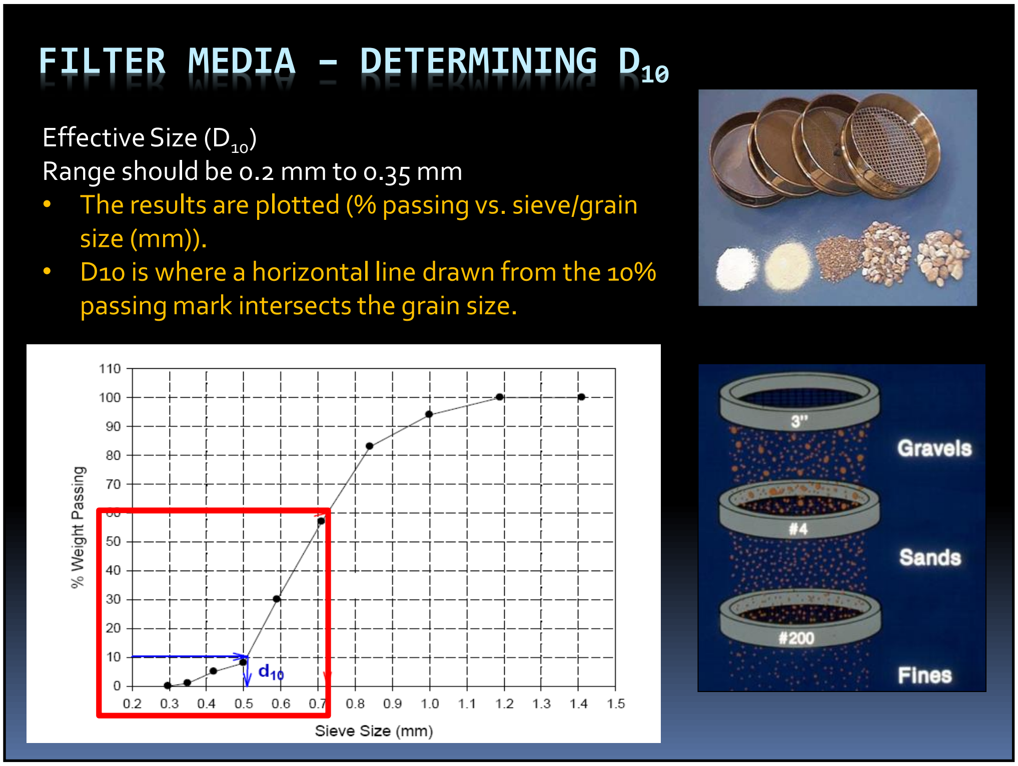
= Σ percentage retained

Percentage passing the sieve:

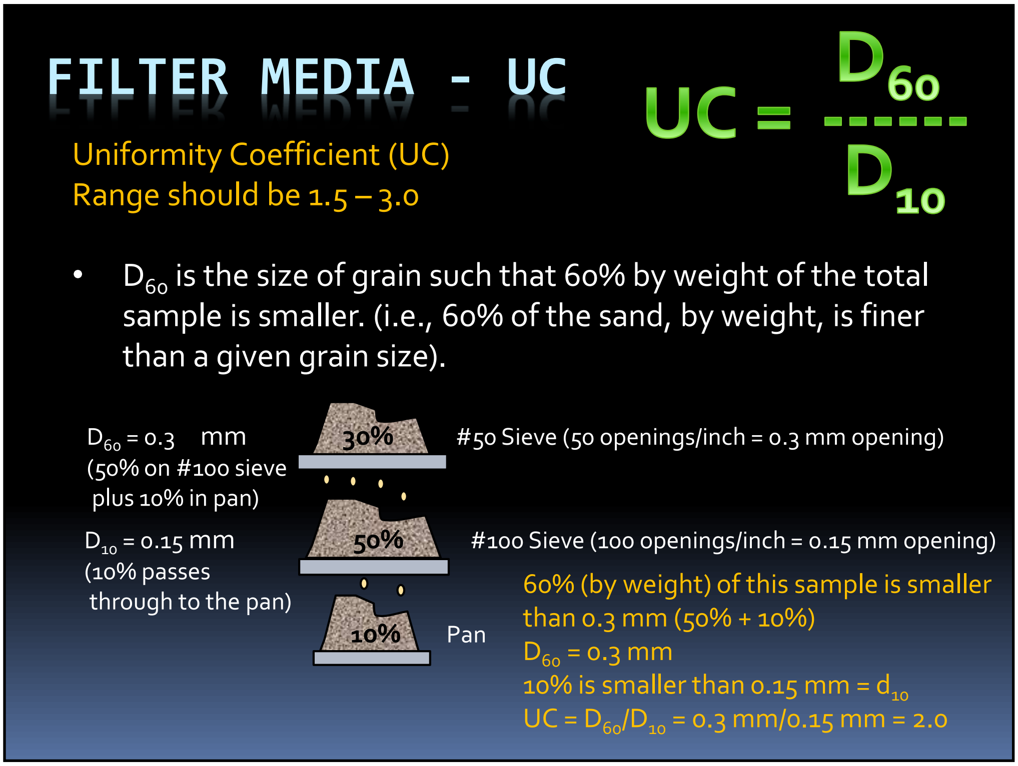
= 100% - Σ percentage retained

Sieve #	Diameter (mm)	Mass of soil retained on each sieve (g)	Percent retained (%)	Cumulative Retained (%)	Percent Passing (%)
20	0.850	5	1.00%	0.00%	100%
30	0.600	27.5	5.50%	5.50%	95%
40	0.425	85	17.00%	22.50%	78%
50	0.300	125	25.00%	47.50%	53%
70	0.212	128	25.50%	73.00%	27%
100	0.150	77.5	15.50%	88.50%	12%
140	0.106	40	8.00%	96.50%	4%
200	0.075	10	2.00%	98.50%	2%
Pan	N/A	2.5	0.50%	99.00%	1%
	Total =>	500 gram sample			

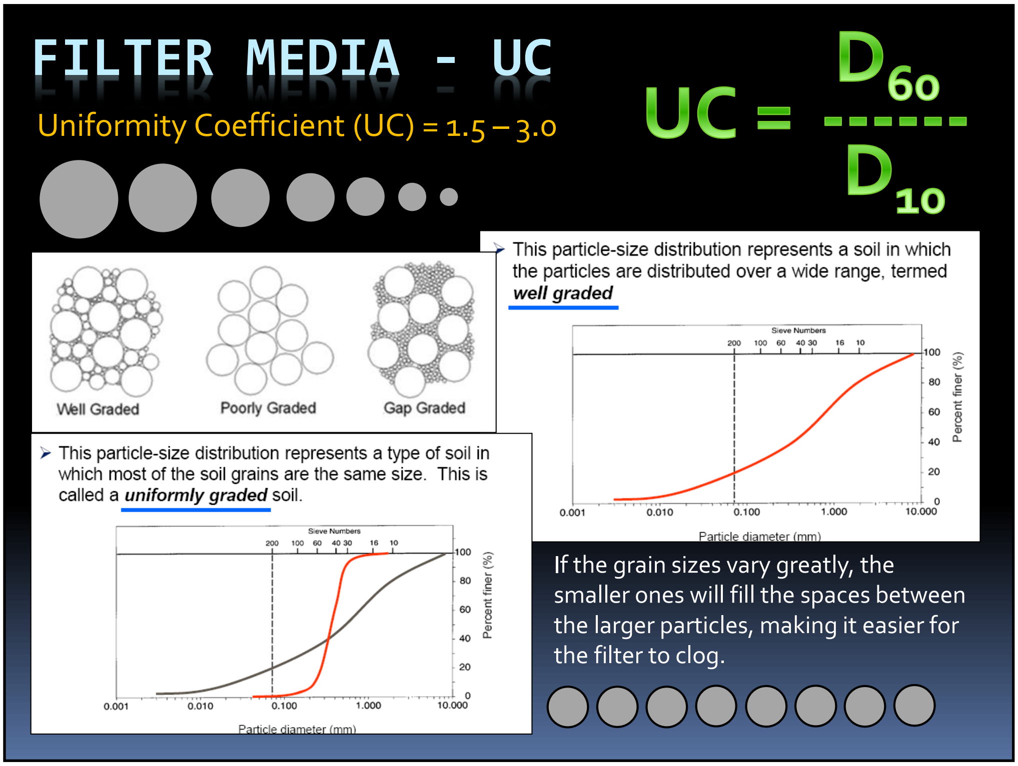
Then you determine the % of the sample, by weight, that passes (is finer than) each successive sieve. This example shows how data from a sieve analysis is tabulated.



The tabulated results are plotted on a graph of % passing versus sieve (i.e., grain size). D_{10} is where a horizontal line drawn from the 10% passing mark intersects the sieve size – that sieve size intersected is the D_{10}.



The uniformity coefficient, denoted by “U” or “C_u”, is determined by dividing D_{60} by D_{10}. Similar to D_{10}, D_{60} is the sieve size through which 60% of the sample by weight passes and 40% is retained. You will not usually see D_{60} referenced, however, it is used to determined the uniformity coefficient, which is an important specification for slow sand filter sand.



The uniformity coefficient is related to the distribution of grain sizes of soils. Uniformly graded soils have soil grains that are mostly the same size. This keeps the pore spaces between the grains open. Well graded sand has a broader size distribution (higher uniformity coefficient), which results in the fines filling up the pore spaces of the media resulting in less space for biological removal mechanisms to work and higher head loss.

FILTER MEDIA – DETERMINING UC

Quiz:

What is D_{10}, D_{60} and UC for this sieve analysis?

Sieve #	Diameter (mm)	Mass of soil retained on each sieve (g)	Percent retained (%)	Cumulative Retained (%)	Percent Passing (%)
20	0.850	0	0.00%	0.00%	100%
30	0.600	30	30%	30%	70%
50	0.300	10	10%	40%	60%
70	0.212	40	40%	80%	20%
100	0.150	10	10%	90%	10%
200	0.075	5	5%	95%	5%
Pan	N/A	5	5%	100%	0%

Quiz – What is d10, d60 and UC for this sieve analysis?

FILTER MEDIA – DETERMINING UC

D10 = 0.15 mm

D60 = 0.3 mm

UC = d60/d10 = 0.3/0.15 = 2.0

Cumulative percentage retained on any sieve:

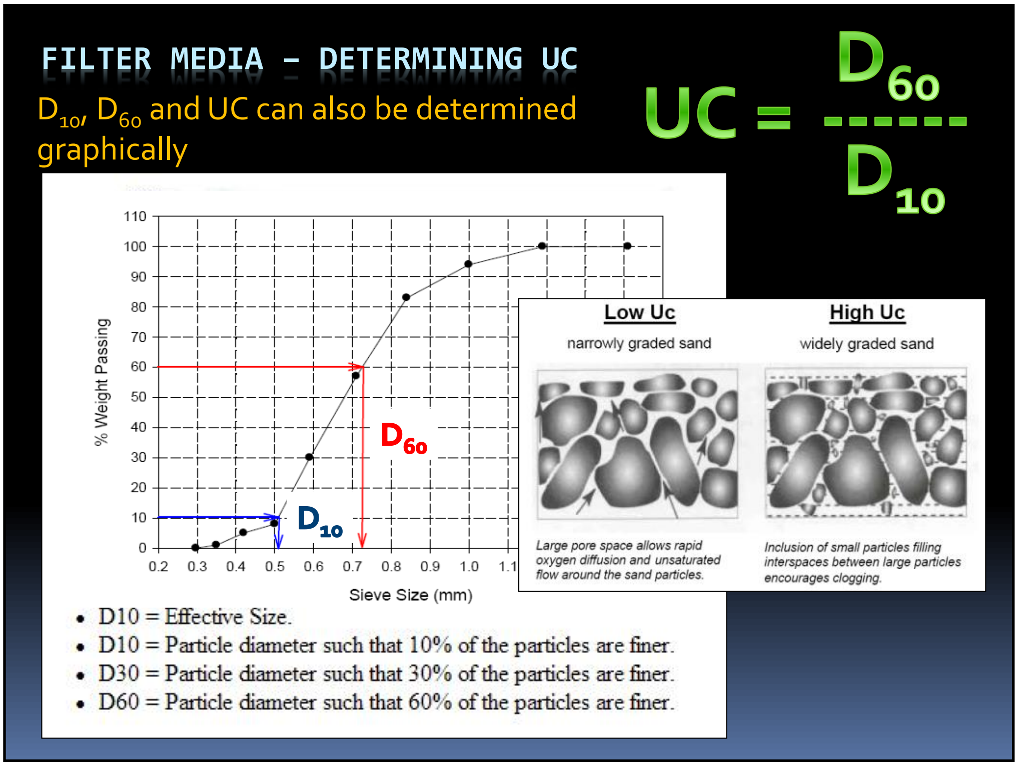
= Σ percentage retained

Percentage passing the sieve:

= 100% - Σ percentage retained

Sieve #	Diameter (mm)	Mass of soil retained on each sieve (g)	Percent retained (%)	Cumulative Retained (%)	Percent Passing (%)	
20	0.850	0	0.00%	0.00%	100%	
30	0.600	30	30%	30%	70%	
50	0.300	10	10%	40%	60%	d60
70	0.212	40	40%	80%	20%	
100	0.150	10	10%	90%	10%	d10
200	0.075	5	5%	95%	5%	
Pan	N/A	5	5%	100%	0%	

Answer: D_{10} = 0.15 mm, D_{60} = 0.3 mm and UC = 0.3/0.15 = 2.0. This example illustrates how the mass retained on each sieve relates to the determination of d10, d60 and UC.

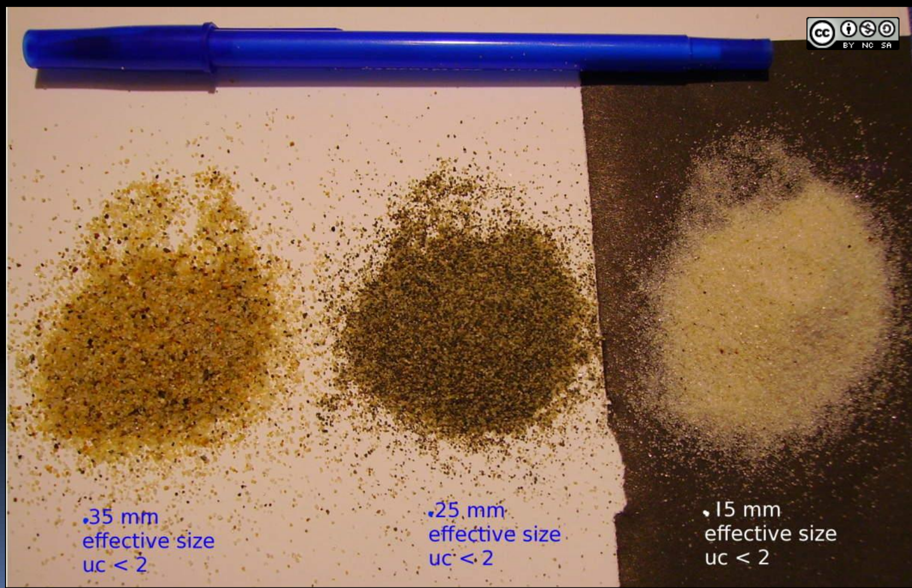


This slide shows how to identify D_{10}, D_{60}, and UC graphically.

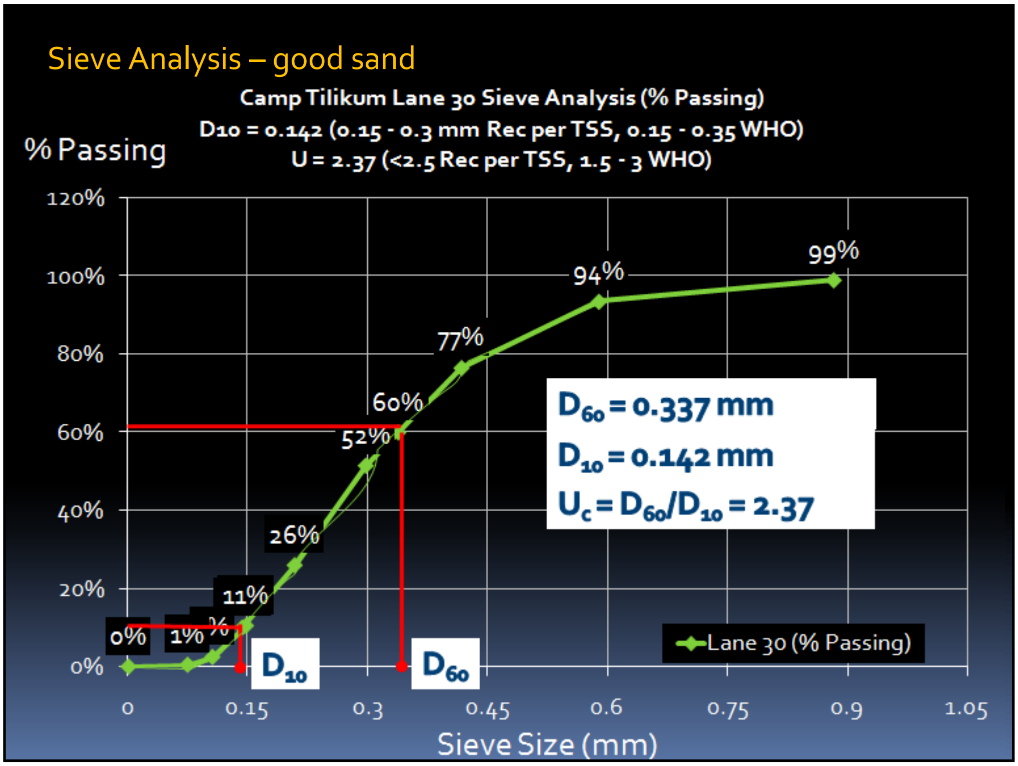
FILTER MEDIA

http://www.slowsandfilter.org

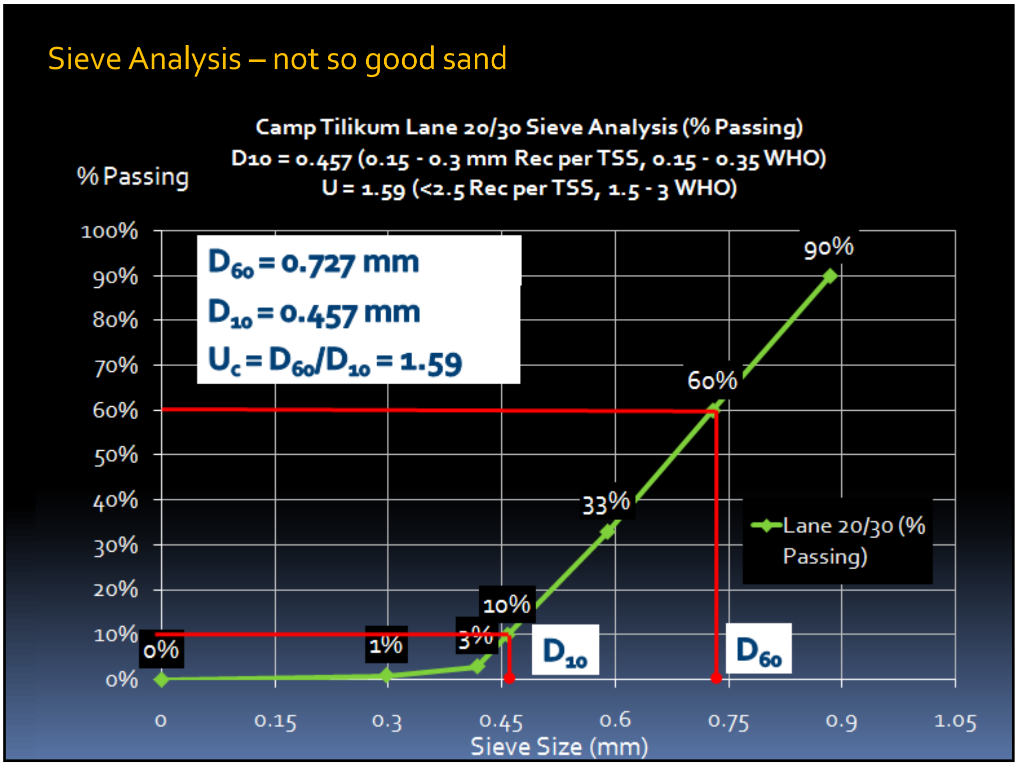
Recommended effective diameter (D_{10}) – 0.2 mm to 0.35 mm



Shown here are sand sizes from 0.15 – 0.35 mm. Photo from www.slowsandfilter.org.



This chart illustrates the results of a sieve analysis for sand primarily within the recommended specifications.



This chart illustrates the results of a sieve analysis for sand with an effective diameter larger than the recommended specification, although the uniformity coefficient is just within the specifications.

OTHER MEDIA CONSIDERATIONS

1. % of fines passing #200 sieve
   < 0.3% by weight
2. Acid solubility
   < 5%
3. Apparent Specific Gravity
   ≥ 2.55
4. Minimum depth
   20-24 inches before re-sanding
5. Availability
   - Local supply options (keep transport costs low)
   - Redundant/backup supply (e.g. 2 or more quarries)
   - Ability to meet specifications
   - Consider ability to clean/stockpile scraped media
6. NSF-61 or equivalent (tested for contaminants)

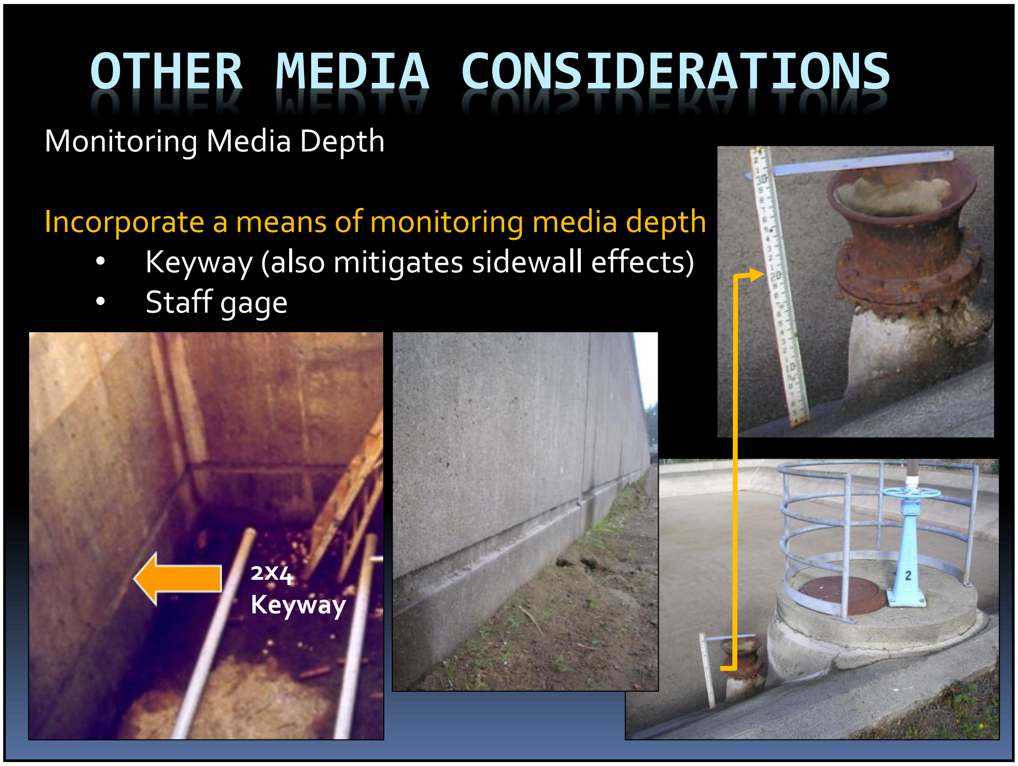
% of fines passing the #200 sieve should not be more than 0.03% by weight. The more fines, the longer it will take for turbidity in a newly sanded filter to clear. Acid solubility should be less than 5%. Media with more acid soluble content, think of limestone, could eventually end up with an undesirable effective diameter or uniformity coefficient in the presence of acidic waters. Sand beds are typically 30 to 36 inches in depth and should not be allowed to drop below 20-24 inches. Some references indicate lower levels may still provide adequate filtration, but as discussed earlier, this may inhibit removal mechanisms that occur deeper in the sand bed. Another thing to consider is where the sand is going to come from. Finding one or more local sources keeps transportation costs low. Not all quarries can provide sand meeting the desired specifications. Some systems have made provisions for cleaning and stockpiling sand that has been removed during the scraping process. This sand should then be analyzed for conformance with the desired characteristics and can then be re-used in subsequent re-sanding efforts.

Sources of Sand

1. CEMEX, Vancouver, WA & Boardman, OR
2. Kleen Industrial Services, Danville, CA
3. Knife River Corporation, Corvallis, OR & Stayton, OR
4. Naselle Rock and Asphalt, Naselle, WA
5. Fazio Brothers, Vancouver, WA

Others???

Some suppliers of slow sand filtration sand.



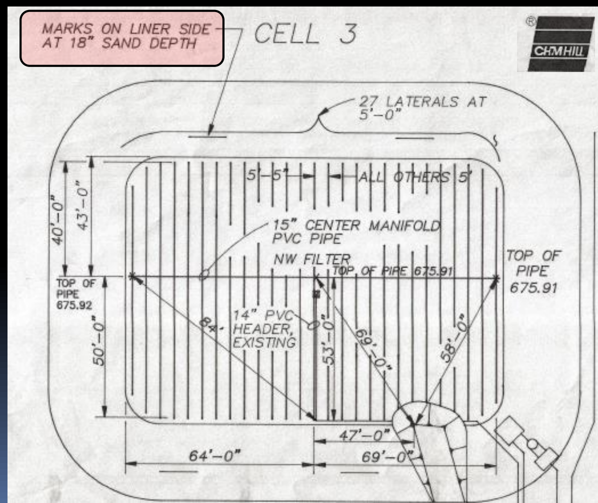
Design should incorporate a way to measure sand bed depth. A keyway can serve to both indicate the minimum sand depth (when the top of the keyway is reached), while interrupting flow down the sidewall.

OTHER MEDIA CONSIDERATIONS

Monitoring Media Depth

Incorporate a means of monitoring media depth

"Marks on Liner Side"



This construction plan shows "marks" at 18" sand depth on the liner of a sloped filter wall (cell #3) for the City of Astoria (1993)

RECOMMENDED MEDIA SPECS

Media specifications (silica sand) - summary

Filter Sand Specification	Recommended Range
Effective Diameter (d10)	0.2 – 0.35 mm
Uniformity Coefficient (U)	1.5 – 3.0
% fines passing #200 sieve	< 0.3% by Wt.
Acid Solubility	< 5%
Apparent Specific Gravity	$\geq$ 2.55
Minimum Depth	20-24 inches
Delivery/Installation	Sand washed prior to installation
NSF/ANSI Standard 61	Certified or equivalent

This table summarizes some of the main specifications for sand and bed depth.

SUPPORT GRAVEL

Support gravel prevents migration of sand down to underdrains, while allowing passage of filtered water.

Proper gradation is key to prevent migration
Rounded rock is used to promote drainage

Example shown* is for a rapid rate plant
(City of Grants Pass)

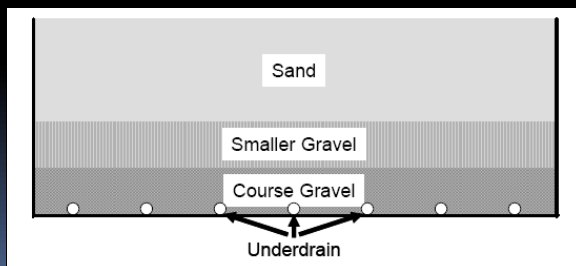
Top Layer 1	Filter sand (Silica sand w/ D_{10} = 0.45 mm- 0.55 mm)
Layer 2	#50 garnet sand
Layer 3	#12 garnet gravel
Layer 4	3/8" x 3/16" gravel
Layer 5	3/4" x 3/8" gravel
Bottom layer	1-1/2" x ¾" gravel

*Anthracite is on top of filter sand, but is not shown.

TEN STATES STANDARDS
SUPPORT GRAVEL

4.3.4.7 Filter gravel

The supporting gravel should be similar to the size and depth distribution provided for rapid rate gravity filters. See 4.2.1.6.f.2. (e.g. 4.3.1.6.e. – Support Media (for rapid rate gravity filters))



TEN STATES STANDARDS
SUPPORT GRAVEL, CONT.

4.3.1.6.e. – Support Media (for rapid rate gravity filters)

4.3.1.6.e.1. Torpedo sand (often used to backfill utility pipes)
A three-inch layer of torpedo sand shall be used as a supporting media for filter sand where supporting gravel is used, and shall have:

a. effective size of 0.8 mm to 2.0 mm (1/32" – 5/64")

b. uniformity coefficient not greater than 1.7.

TEN STATES STANDARDS

SUPPORT GRAVEL, CONT.

4.3.1.6.e.2. Gravel - Gravel, when used as the supporting media shall consist of cleaned and washed, hard, durable, rounded silica particles and shall not include flat or elongated particles. The coarsest gravel shall be 2.5 inches in size when the gravel rests directly on a lateral system, and must extend above the top of the perforated laterals. Not less than four layers of gravel shall be provided in accordance with the following size and depth distribution:

Size	Depth
3/32 to 3/16 inches	2 to 3 inches
3/16 to 1/2 inches	2 to 3 inches
1/2 to 3/4 inches	3 to 5 inches
3/4 to 1 ½ inches	3 to 5 inches
1 ½ to 2 ½ inches	5 to 8 inches

Reduction of gravel depths and other size gradations may be considered upon justification to the reviewing authority for slow sand filtration or when proprietary filter bottoms are specified.

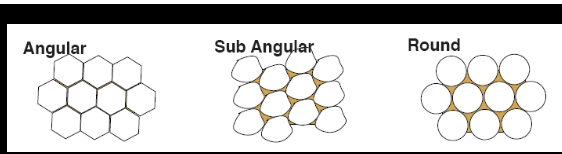
SAND & GRAVEL

ASTM E11 standard sizes for woven wire test sieve cloth

No.	Mesh Size (mm)	No.	Mesh Size (mm)	No.	Mesh Size (mm)	No.	Mesh Size (mm)
1″	25.0	7	2.80	20	0.85	60	0.250
¾″	19.0	8	2.36	25	0.71	80	0.180
½″	12.5	10	2.00	30	0.60	100	0.150
3/8″	9.5	12	1.70	35	0.50	120	0.125
4	4.75	14	1.40	40	0.425	140	0.106
5	4.00	16	1.18	45	0.355	170	0.090
6	3.35	18	1.00	50	0.300	200	0.075

There are standard mesh sizes for grading sand and gravel. Some of these mesh sizes likely to be used in slow sand filters identified under ASTM E11 are shown here for reference.

SUPPORT SAND

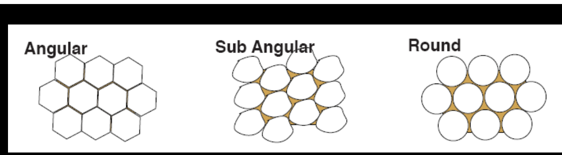


Concrete Sand
(a.k.a. "Torpedo Sand")

- Fine Aggregate grade 1 or 2 (FA-1 or 2)
- Angular to sub-angular
- 3/8" x #100 mesh (9.5 x 0.15 mm)
- Washed and screened
- Used in production of ready mixed concrete
- Commonly used for pipe bedding & Backfill
- Meets ASTM C33 standard

Photos of gravel from Phil's Topsoil, Inc.,
http://www.philstopsoil.com/stone_and_sand.html

SUPPORT GRAVEL



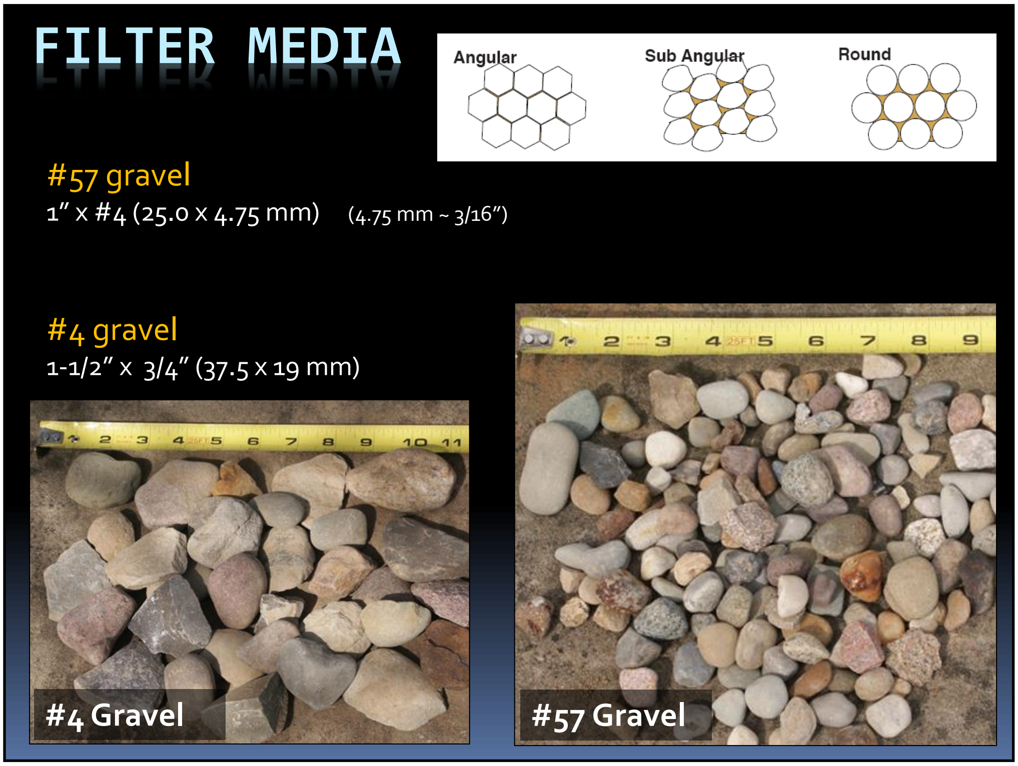
Pea Gravel (CA-16)

- Round to sub-angular river rock
- 3/8" x #16 (9.5 x 1.18 mm)
  (1.18 mm ~ 3/64")
- Washed but may contain smaller sediment
- Commonly used for decorative landscaping,
- retaining wall backfill, or where finer aggregates are needed when drainage through stone is
- desired.

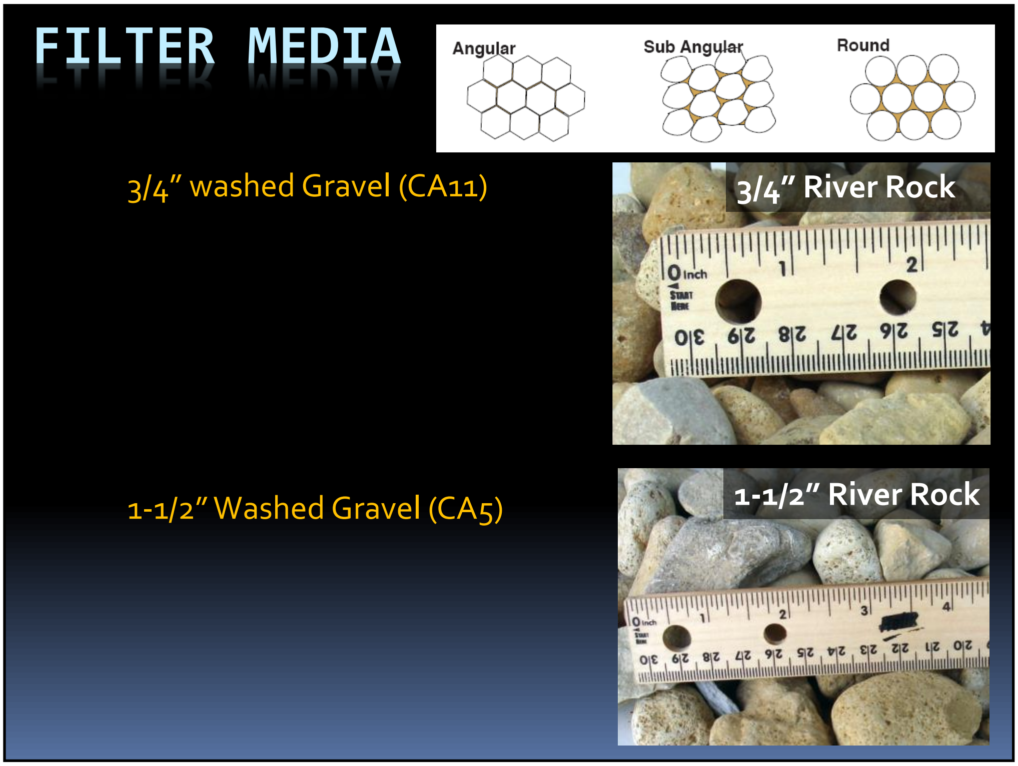
#8 Gravel (a.k.a. #8 pea gravel)

3/8" x #8 (9.5 x 2.36 mm) (2.36 mm ~ 3/32")

Top photo of gravel from Phil's Topsoil, Inc., http://www.philstopsoil.com/stone_and_sand.html
Bottom photo of gravel from The Gravel Guy – Don Brown. http://thegravelguy.com/gravel/



Photos of gravel from The Gravel Guy – Don Brown. http://thegravelguy.com/gravel/



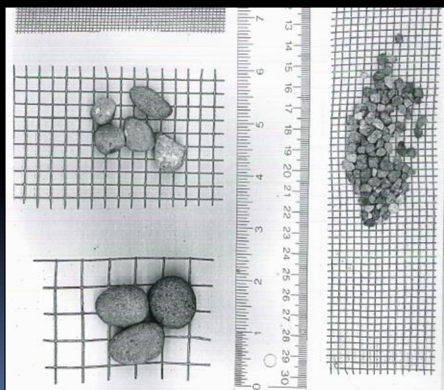
Photos of gravel from Phil's Topsoil, Inc., http://www.philstopsoil.com/stone_and_sand.html

SUPPORT MEDIA

City of Salem, OR

Filter sand D_{10} = 0.27 – 0.33 mm
4″ Top Layer #4 x #8 sieve
4″ Middle Layer 1/2″ x #4 sieve (3/16″)
10″ Bottom Layer 7/8″ x 1/2″

Gravel Layer	d_{10} Size	d_{90} Size
Top 4 inches	No. 8 sieve (2.36 mm)	No. 4 sieve (4.75 mm)
Middle 4 inches	No. 4 sieve (4.75 mm)	0.5 inches
Bottom 10 inches	0.5 inches	0.875 inches



SUPPORT MEDIA

3 layers of support gravel can be adequate, but 4 or more layers is recommended due to product and placement uncertainties.

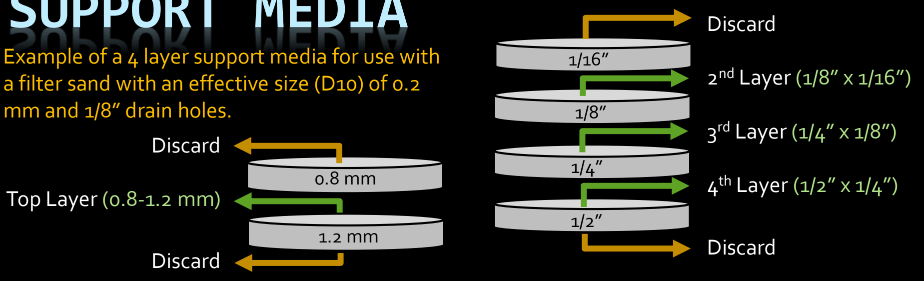
Layer	D10 (mm)	D90 (mm)	Depth (inches)
Top Layer	3/64" (1.0 mm)	1/16" (1.4 mm)	6
Middle Layer	5/32" (4.0 mm)	7/32" (5.6 mm)	6
Bottom Layer	5/8" (16 mm)	29/32" (23 mm)	6
Each successive layer should be graded so that its smaller (D_{10}) particle diameters are not more than four times smaller than those of the layer immediately below.			
The grains of the bottom layer should have an effective diameter of at least twice the size of the drain holes or slots.			

Considerations
Durability
Cost
Availability

* The gravel support using three layers as specified will work if the orifices into the under drain pipe are less than 8 mm in diameter. If the orifices are larger, more than three layers of gravel may be needed.

SUPPORT MEDIA

Example of a 4 layer support media for use with a filter sand with an effective size (D10) of 0.2 mm and 1/8" drain holes.



Support media for use with a filter sand with an effective size (d10) of 0.2 – 0.35 mm and 1/8" underdrain holes (for ¼" underdrain holes a fifth layer of ¾" x ½" or 1" x ½" gravel is needed).

Layer	Size Range		Depth (inches)	Specification
Top Layer	1/32" (0.8 mm)	1/21" (1.2 mm)	3	Largest Size/Smallest Size = 1.5 Smallest Size in Top Layer /D_{10} Filter Sand = 4.0
2nd Layer 1/8" x 1/16"	1/16" (1.588 mm)	1/8" (3.175 mm)	3	Largest Size/Smallest Size = 2.00 Largest Size/Smallest Size of Top Layer = 3.97
3rd Layer 1/4" x 1/8"	1/8" (3.175 mm)	1/4" (6.35 mm)	3	Largest Size/Smallest Size = 2.00 Largest Size/Smallest Size of 2nd Layer = 4.00
4th Layer 1/2" x 1/4"	1/4" (6.35 mm)	1/2" (12.7 mm)	Embed and bury underdrain piping with 1" of cover	Largest Size/Smallest Size = 2.00 Largest Size/Smallest Size of 3rd Layer = 4.00 Smallest Size = 2x Drain Diameter

SUPPORT MEDIA

4-5 Layer Option

Filter sand D_{10} = 0.2 mm
3" Top Layer #20 sand
3" Second Layer 1/8" x 1/16"
3" Third Layer 1/4" x 1/8"
3" Fourth Layer ½" x ¼" (4 layers work with 1/8" drain holes)
Bottom Layer ¾" x ½" (5 layers are needed with ¼" drain holes)

4-5 Layer Option	d10 (mm)	d90 (mm)	d10 (in)	d90 (in)	AWWA B100-09 & WHO d10 > 2xDrain?	AWWA B100-09 d10 top gravel between 4 and 4.5 times d10 sand	WHO (Huisman & Wood) d10 lower/d10 upper (≤3 where d90/d10 of same layer ≤ 2 **or** ≤ 4 if d90/d10 of same layer ≤ 1.4)	AWWA B100-09 d90 lower/d10 upper (≤4)	AWWA B100-09 d90/d10 same layer (≤2) (≤ 1.4, WHO)
Sand	0.2	N/A			N/A	N/A	N/A	N/A	N/A
Top Gravel	0.8	1.2	1/32	1/21	No	4.00	4.00	N/A	1.50
2nd Gravel	1.5875	3.175	1/16	1/8	No	N/A	1.98	3.97	2.00
3rd Gravel	3.175	6.35	1/8	1/4	No	N/A	2.00	4.00	2.00
4th Gravel	6.35	12.7	1/4	1/2	Yes	N/A	2.00	4.00	2.00
5th Gravel	12.7	19.05	1/2	3/4	Yes	N/A	2.00	3.00	1.50
Drain	3.175	N/A	1/8		N/A	N/A	N/A	N/A	N/A

SUPPORT MEDIA

Rapid Rate Filter (City of Grants Pass)

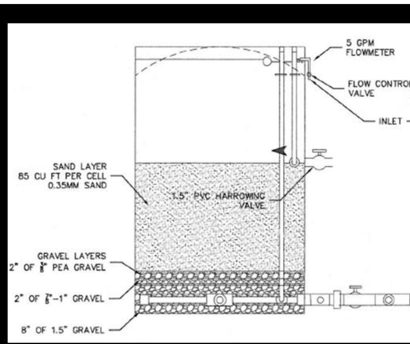
Top Layer 1 (#50 garnet sand w/ D_{10} = 0.25 mm)
Layer 2 #12 garnet gravel
Layer 3 3/8" x 3/16" gravel
Layer 4 3/4" x 3/8" gravel
Bottom layer 1-1/2" x ¾" gravel

Grants Pass using Garnet Sand as Filter Medium	d10 (mm)	d90 (mm)	d10 (in)	d90 (in)	**AWWA B100-09 & WHO** d10 > 2xDrain?	**AWWA B100-09** d10 top gravel between 4 and 4.5 times d10 sand	**WHO (Huisman & Wood)** d10 lower/d10 upper (≤3 where d90/d10 of same layer ≤ 2 **or** ≤ 4 if d90/d10 of same layer ≤ 1.4)	**AWWA B100-09** d90 lower/d10 upper (≤4)	**AWWA B100-09** d90/d10 same layer (≤2) **(≤ 1.4, WHO)**
Sand	0.25	N/A			N/A	N/A	N/A	N/A	N/A
Top Gravel	1.18	1.7	2/43	1/15	No	4.72	4.72	N/A	1.44
2nd Gravel	4.7625	9.5	3/16	3/8	No	N/A	4.04	8.05	1.99
3rd Gravel	9.5	19.05	3/8	3/4	No	N/A	1.99	4.00	2.01
4th Gravel	19.05	38.1	3/4	1 1/2	Yes	N/A	2.01	4.01	2.00
5th Gravel			0	0	No	N/A	0.00	0.00	#DIV/0!
Drain	6.35	N/A	1/4		N/A	N/A	N/A	N/A	N/A

SUPPORT MEDIA

Opal Creek, OR (Blue Future Filters)

Filter sand D_{10} = 0.3 mm
2" Top Layer 3/8" x 3/16"
2" Middle Layer 1" x 7/8" (or 1" x 1/2")
8" Bottom Layer 1-1/2" x 3/4"
Drain orifice = ¼" slots



Opal Creek, Oregon (Blue Future Filters)	d10 (mm)	d90 (mm)	d10 (in)	d90 (in)	**AWWA B100-09 & WHO** d10 > 2xDrain?	**AWWA B100-09** d10 top gravel between 4 and 4.5 times d10 sand	**WHO (Huisman & Wood)** d10 lower/d10 upper ($\le$3 where d90/d10 of same layer $\le$ 2 **or** $\le$ 4 if d90/d10 of same layer $\le$ 1.4)	**AWWA B100-09** d90 lower/d10 upper ($\le$4)	**AWWA B100-09** d90/d10 same layer ($\le$2) **($\le$ 1.4, WHO)**
Sand	0.35	N/A			N/A	N/A	N/A	N/A	N/A
Top Gravel	3.175	9.525	1/8	3/8	No	9.071429	9.07	N/A	3.00
2nd Gravel	22.25	25.4	7/8	1	Yes	N/A	7.01	8.00	1.14
3rd Gravel	19.05	38.1	3/4	1 1/2	Yes	N/A	0.86	1.71	2.00
4th Gravel			0	0	No	N/A	0.00	0.00	#DIV/0!
5th Gravel			0	0	No	N/A	#DIV/0!	#DIV/0!	#DIV/0!
Drain	6.35	N/A	1/4		N/A	N/A	N/A	N/A	N/A

SUPPORT MEDIA

City of Salem, OR

Filter sand D_{10} = 0.27 – 0.33 mm
4" Top Layer #4 x #8 sieve
4" Middle Layer 1/2" x #4 sieve (3/16")
10" Bottom Layer 7/8" x 1/2"

Gravel Layer	d_{10} Size	d_{90} Size
Top 4 inches	No. 8 sieve (2.36 mm)	No. 4 sieve (4.75 mm)
Middle 4 inches	No. 4 sieve (4.75 mm)	0.5 inches
Bottom 10 inches	0.5 inches	0.875 inches

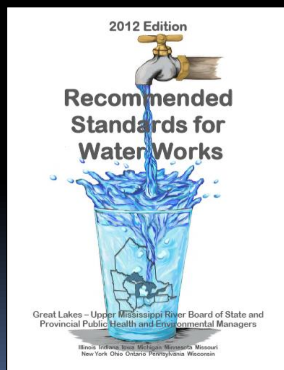
City of Salem, Oregon	d10 (mm)	d90 (mm)	d10 (in)	d90 (in)	**AWWA B100-09 & WHO** d10 > 2xDrain?	**AWWA B100-09** d10 top gravel between 4 and 4.5 times d10 sand	**WHO (Huisman & Wood)** d10 lower/d10 upper (≤3 where d90/d10 of same layer ≤ 2 **or** ≤ 4 if d90/d10 of same layer ≤ 1.4)	**AWWA B100-09** d90 lower/d10 upper (≤4)	**AWWA B100-09** d90/d10 same layer (≤2) **(≤ 1.4, WHO)**
Sand	0.27	N/A			N/A	N/A	N/A	N/A	N/A
Top Gravel	2.36	4.75	4/43	3/16	No	8.740741	8.74	N/A	2.01
2nd Gravel	4.75	12.7	3/16	1/2	No	N/A	2.01	5.38	2.67
3rd Gravel	12.7	22.25	1/2	7/8	Yes	N/A	2.67	4.68	1.75
4th Gravel			0	0	No	N/A	0.00	0.00	#DIV/0!
5th Gravel			0	0	No	N/A	#DIV/0!	#DIV/0!	#DIV/0!
Drain	6	N/A	17/72		N/A	N/A	N/A	N/A	N/A

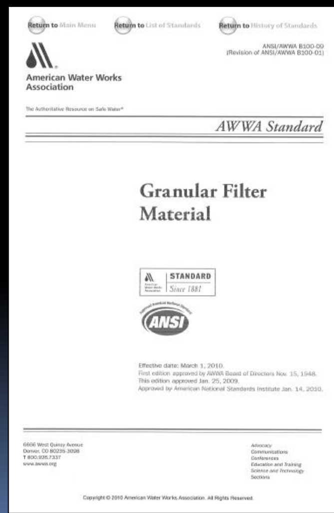
SUPPORT MEDIA

More layers of support gravel is often needed, due to product cost and availability.

For material size and layer depth, follow the latest:

1. Guidelines in Appendix D of ANSI/AWWA B100 Standard; or
2. Ten States Standards for slow sand filter construction





SUPPORT MEDIA

Support Media Installation

1. For material washing/handling/delivery/installation recommendations, follow the ANSI/AWWA B100 Standard

3. Desired layer elevations should be marked on filter wall and each layer added and screeded level and even with the mark.

4. The elevation of the top surface of each layer shall be checked using water that is introduced into the filter as a guide with the media within $\pm$ 0.5 inch of the desired level and the areas above and below the desired level within 10% of each other.

5. Support gravel should washed prior to placement of filter sand (see AWWA B100 Standard).

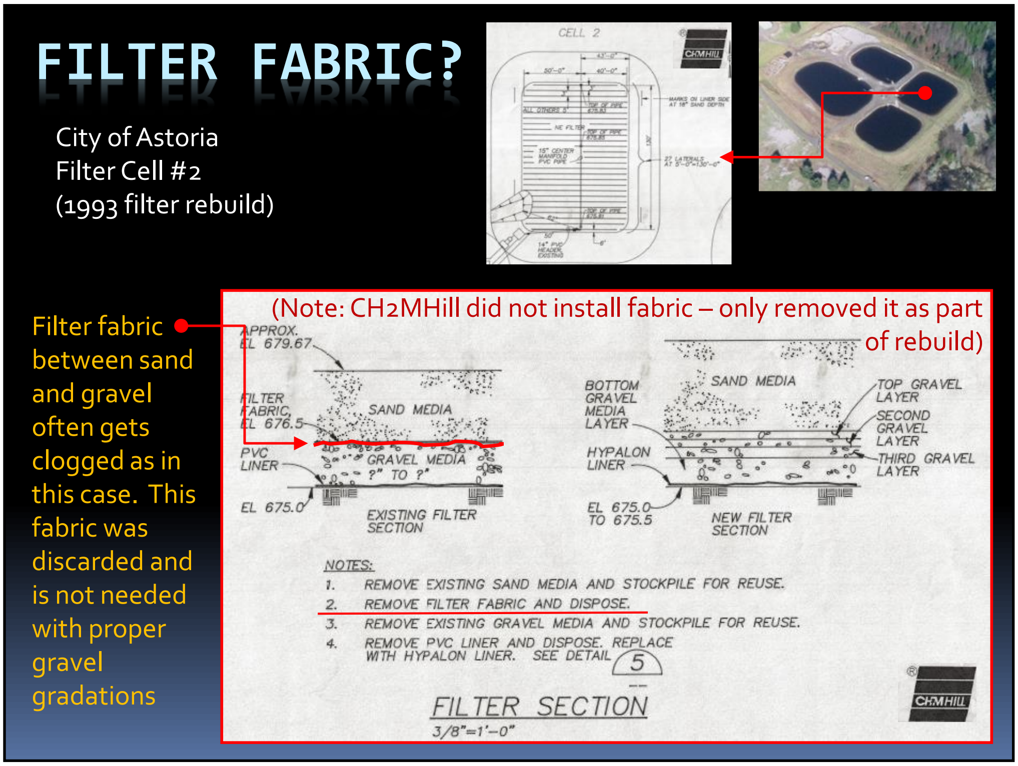
American Water Works Association

AWWA Standard

Granular Filter Material

STANDARD

ANSI



A filter fabric layer originally installed for filter cell #2 for the City of Astoria, Oregon was later removed in 1993 due to clogging.

TEN STATES STANDARDS
SUPERNATANT WATER (HEADWATER)

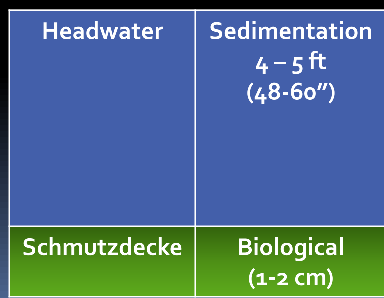
4.3.4.8 Depth of water on filter beds

Design shall provide a depth of at least 3 – 6 feet of water above the sand. Influent water shall not scour the sand surface.

Wickiup Water District, OR

HEADWATER

- Purpose is to provide driving head
- Provides retention/settling
- Little benefit to exceeding a depth of 4-5 feet
- Shallow levels may increase algae due to sunlight penetration
- Important to include:
  1. Side stream influent piping if harrowing
  2. Overflow
  3. Drain
  4. Backflush piping



INFLUENT ENERGY DISSIPATION

"Influent water shall not scour the sand surface"

Energy Dissipation (to avoid sand scouring)

Energy dissipation helps to keep sand from scouring and erosion of the filter cell liner.

2011. City of Corbett, OR

This is filter influent piping for the City of Corbett, OR.

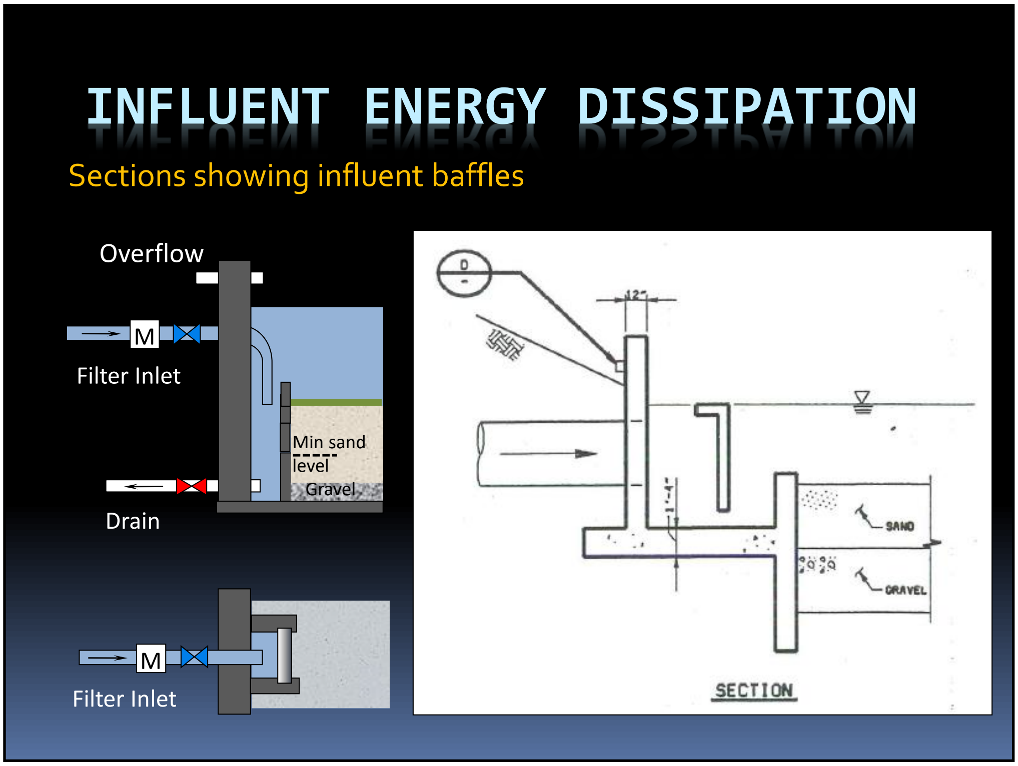
INFLUENT ENERGY DISSIPATION

Jewell School District #8 (Clatsop Co)

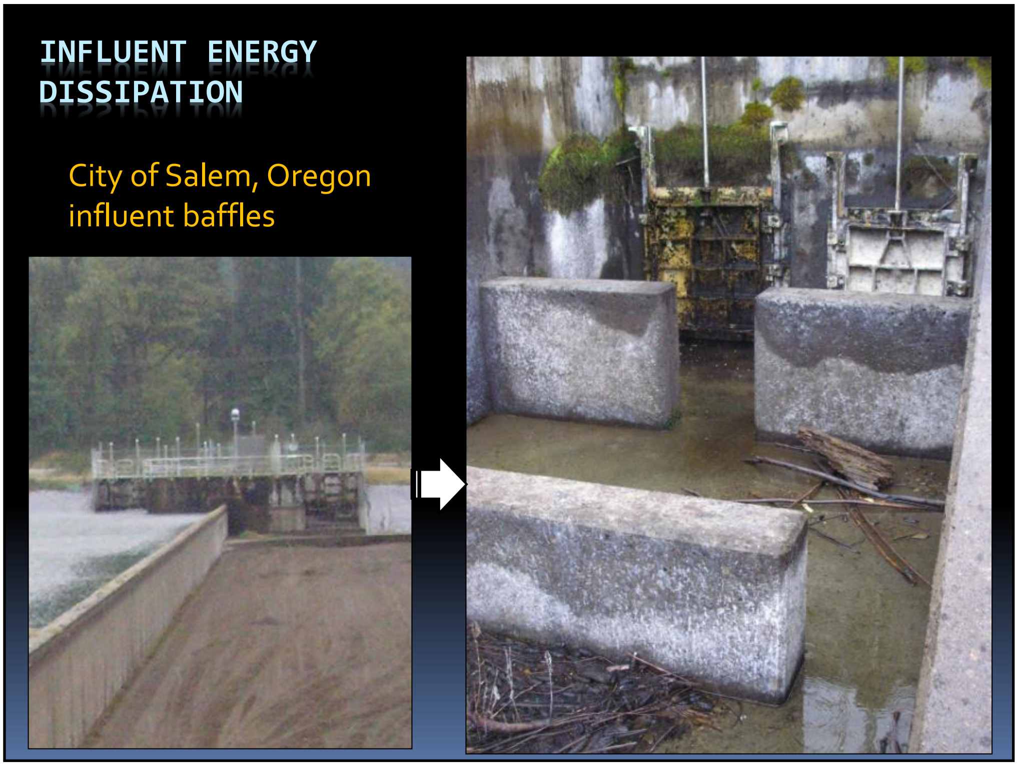
3 cells (Blue Future)
18 gpm (0.1 gpm/sf)
Completed in 2010
Cleaned using wet harrowing

Even in smaller covered filters, influent energy should be minimized.

This picture shows a splash plate under the inlet piping for an enclosed slow sand filter for the Jewell School District #8 in Clatsop County, Oregon.



These designs allow influent water to enter a filter bed without the risk of scouring the sand bed.



These designs allow influent water to enter a filter bed without the risk of scouring the sand bed.

TEN STATES STANDARDS
MONITORING & INFLUENT CONTROLS

4.3.4.9 Control appurtenances

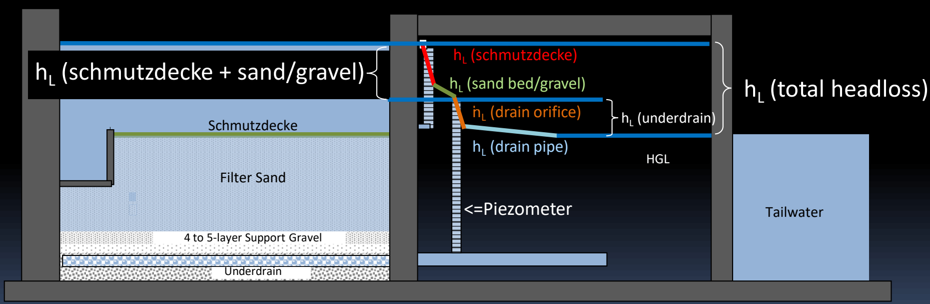
Each filter shall be equipped with:

a. Influent and effluent sampling taps;
b. An indicating loss of head gauge or other means to measure head loss;
c. An indicating rate-of-flow meter. A modified rate controller that limits the rate of filtration to a maximum rate may be used. However, equipment that simply maintains a constant water level on the filters is not acceptable, unless the rate of flow onto the filter is properly controlled. A pump or flow meter in each filter effluent line may be used as the limiting device for the rate of filtration only after consultation with the reviewing authority.

HEADLOSS MEASUREMENT

Piezometers

Measurement of head loss can be accomplished with simple piezometers mounted outside the filter and tailwater structures.



Screened probes at the top and bottom of the filter sand can allow easy measurement of head loss with simple piezometers mounted outside the filter. This diagram illustrates how headloss is greatest in the schumtzdecke and top few centimeters of sand towards the end of the filter run. This diagram also shows how design ensures an even distribution of flow by having a much higher headloss through the drain pipe orifices compared to the underdrain piping.

TEN STATES STANDARDS
EFFLUENT CONTROLS

4.3.4.9 Control appurtenances, continued

Each filter shall be equipped with:

d. Provisions for filtering to waste with appropriate measures for cross connection control;
e. An orifice, Venturi, or other suitable means of discharge measurement installed on each filter to control the rate of filtration.
f. An effluent pipe designed to maintain the water level above the top of the filter sand.

KEY FLOW CONTROL ELEMENTS

Key flow control elements:

1. Effluent weir or controls to prevent air entrainment
2. Ability to fill from the top with raw water or the bottom with filtered water from another cell – a flow meter is needed to control this flow to a rate of 0.3 – 0.6 ft of filter bed per hour (0.0374 – 0.0748 gpm/ft^2).
3. Continuous operation (constant supply of nutrients)
4. Gradual flow rate changes (ideally no more often than weekly or monthly)
5. Flexibility to change sources or use various combinations of filter beds

FILTRATION RATE

Filtration rate should be continuous

1. Good for dissolved oxygen
2. Good for nutrient supply
3. Good for biological mechanisms
4. Influent flow should not scour sand surface
5. 0.1 gpm/ft^2 maximum filtration rate
6. 0.03 gpm/ft^2 minimum filtration rate
7. Cold temperatures may need lower filtration rates (e.g., 0.05 gpm/ft^2 when water temp < 5°C)
8. Controls should be in place to prevent the tail water (effluent side) from dropping below the sand bed during operation (e.g., an effluent weir) – this helps prevent vacuum conditions and air entrainment.

The filtration rate should be continuous with rate changes needed to accommodate system demands made gradually over a period of several days or weeks. Operating this way keeps a constant supply of nutrients and dissolved oxygen needed for healthy biological activity. Filtration rates should not exceed 0.1 gpm/ft^2 and should not drop below 0.03 gpm/ft^2.

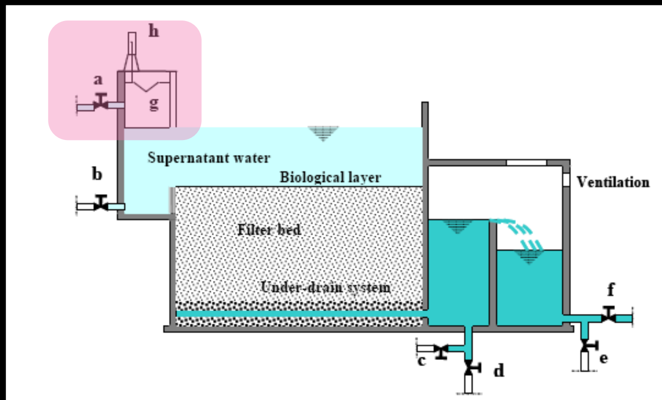
FLOW CONTROL –INLET VS OUTLET

Flow control can be practiced at the inlet or outlet. Inlet flow control can be either operated as constant rate or declining rate modes.

1. Inlet flow Control – Constant Rate
   Uses a throttling valve plus a flowmeter or V-notch weir prior to each filter. The operator uses the flow control valve to set the desired filtration rate. As the resistance of the filter bed increases, the water level rises. When the headwater level approaches the overflow pipe the bed should be cleaned.
   - Requires less operator involvement
   - Ensures a more constant rate of filtration
   - Allows operator to see headloss development as headwater rises
   - Low headwater at the beginning of filter runs may make filters more vulnerable to freezing in the winter if filters are not covered or insulated
2. Inlet Flow Control – Declining Rate
   Uses a hydraulic control valve with a flowmeter and valve at the raw water line prior to each filter that regulates flow while maintaining a constant water surface elevation above the filter. Effluent flow decreases as the filter plugs.
   - Headwater level is not indicative of headloss development (piezometers or pressure gages are needed)
   - Decline in effluent rate or approach to terminal headloss indicates cleaning

INLET FLOW CONTROL

Inlet (Influent) Control



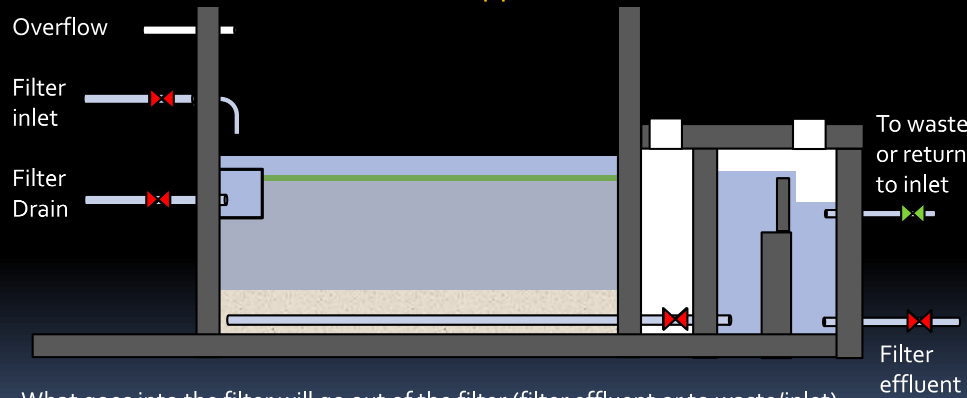
Basic components of an inlet controlled slow sand filter

a. Valve for raw water inlet and regulation of filtration rate
b. Valve for draining supernatant water layer
c. Valve for backfilling the filter bed with clean water
d. Valve for draining the filter bed and outlet chamber
e. Filter to waste valve
f. Valve for delivery of treated water to the disinfection clear well
g. Inlet weir
h. Calibrated flow indicator

Influent control regimes use a weir box and/or valves to control the flow of water into the filter. The outlet weir structure is still in use to ensure that the water level never drops below the sand bed during normal operation.

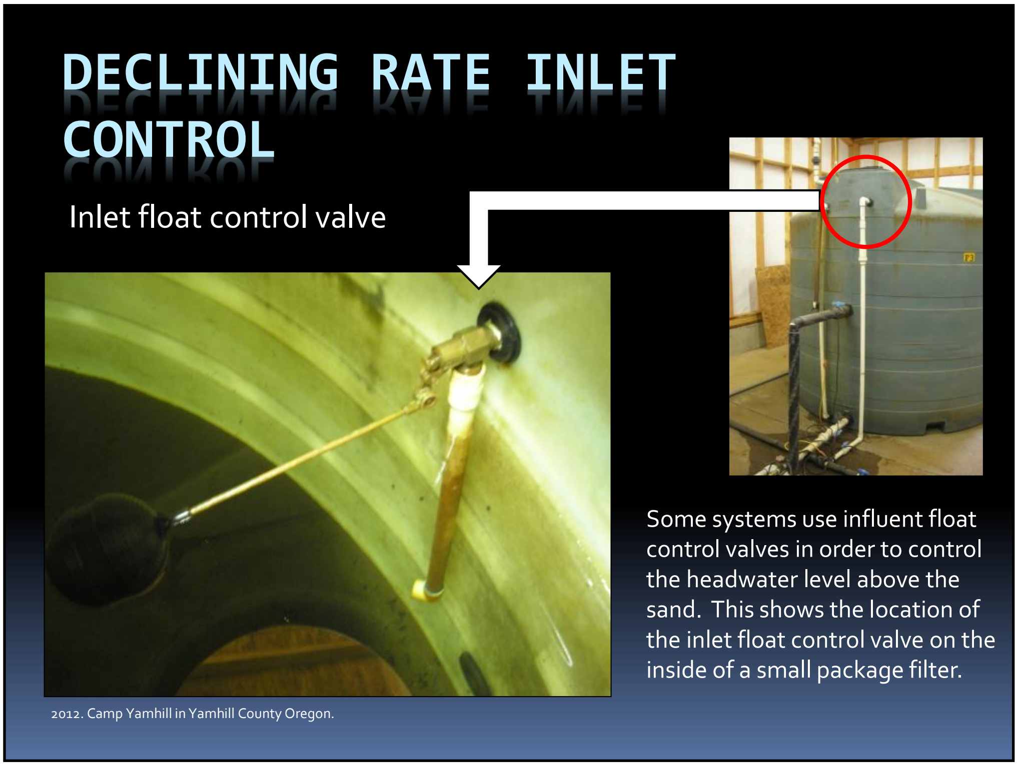
CONSTANT RATE INLET CONTROL

- Starts off with a lower headwater level
- Influent valve is set to the desired rate (e.g., 0.03-0.1 gpm/ft²)
- Outlet valve is fully open
- The filter will need to be cleaned when the headwater approaches the overflow



What goes into the filter will go out of the filter (filter effluent or to waste/inlet)
Headloss builds up towards the end of the filter run as it plugs up causing headwater to rise
Cleaning unplugs filter allowing headwater to drop
Excess water produced is re-circulated (pumped) to influent or sent to waste (gravity)

In inlet controlled filters, the rate of filtration is set by the filter inlet valve. Once the desired rate is set, no further adjustment of the valve is needed. At first the headwater level will be relatively low, but will gradually rise as the filter plugs. Once the level has reached the scum outlet or overflow, the filter has to be cleaned. Inlet control reduces the amount of work and keeps a constant rate of delivery of water into the filter.



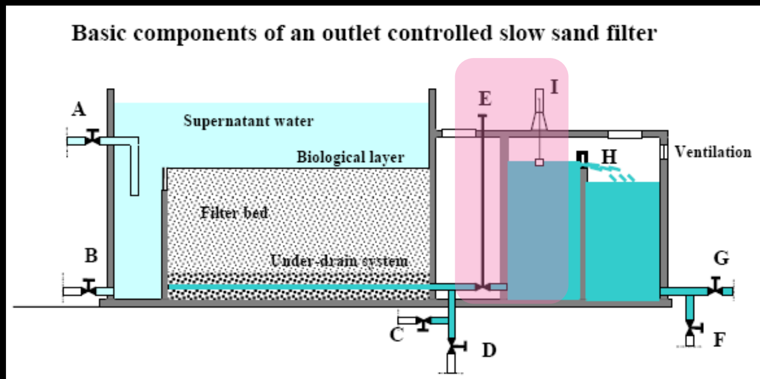
Some systems use influent float control valves in order to control the headwater level above the sand. This shows the location of the inlet float control valve on the inside of a small package filter. [This photo is from Camp Yamhill in Yamhill County, Oregon.]

FLOW CONTROL –INLET VS OUTLET

3. Outlet Flow Control (declining rate)
   Uses a control valve and flowmeter on the outlet pipe from each filter. As the filter plugs, the filtration rate will decrease, even if the headwater level is increased. The level of water on top of the filter can be controlled by using float switches to turn on and off raw water pumps or control inlet control valves. Excess water can also be diverted out an overflow and directed back to the source.
   - Most common.
   - Fairly simple control method although operator involvement is higher if no automation is used.
   - Higher rates may be implemented faster for emergency situations, since you don't have to wait for headwater to rise as with constant rate influent control.
   - Ability to maintain higher headwater level provides better protection from freezing.
   - Higher headwater level provides raw water storage should influent flows be interrupted due to power failure or intake shutdown due to damage or to avoid high turbidity events.
   - Headwater level is not indicative of headloss development (piezometers or pressure gages are needed)

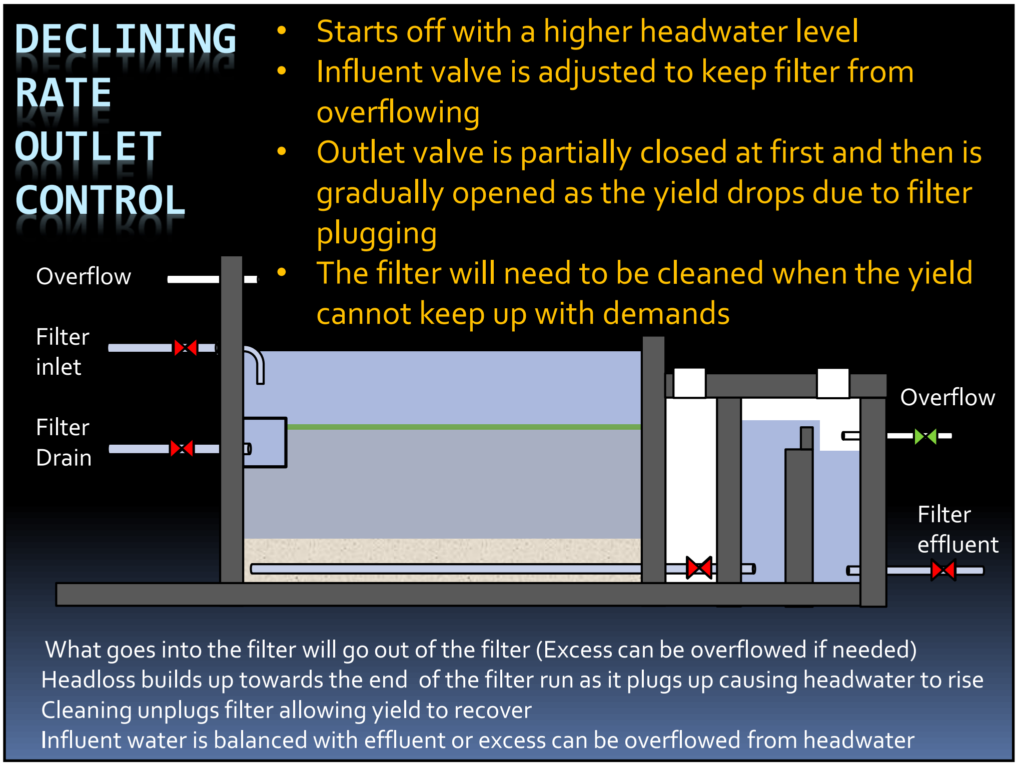
OUTLET FLOW CONTROL

Outlet (effluent) control is most common



A. Raw water inlet valve
B. Valve for draining supernatant water layer
C. Valve for backfilling the filter bed with clean water
D. Valve for draining the filter bed and outlet chamber
E. Valve for regulation of the filtration rate
F. Filter to waste valve
G. Valve for delivery of treated water to the disinfection clear well
H. Outlet weir
I. Calibrated flow indicator

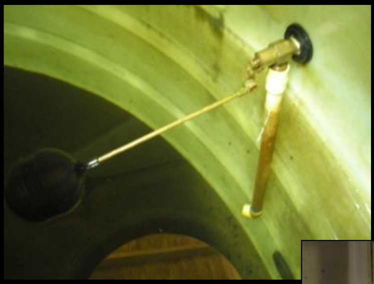
Effluent control regimes use a weir box and/or valves to control the flow of water out of the filter. The outlet weir structure ensures that the water level never drops below the sand bed during normal operation. This prevents a vacuum from developing and air being entrained in the sand bed should headloss due to plugging increase to high levels.



In outlet control, the effluent is restricted at the beginning of the filter fun to keep flows down to 0.1 gpm/sf or less, while the headwater level is maintained by adjusting the filter inlet. Daily or every couple of days the valve has to be opened a little further to compensate for the increase in headloss, causing a slight variation in the rate of filtration. Inlet and outlet flows have to adjusted periodically to balance flows into and out of the filter throughout the filter run.

VALVES

Select valves for the purpose they are intended to serve and the pressures they are needed to withstand



Float control valve. Camp Yamhill in Yamhill Co. Oregon. 2012.

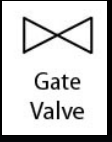
Telescoping Valve. City of Cannon Beach in Clatsop Co. Oregon. 2013.

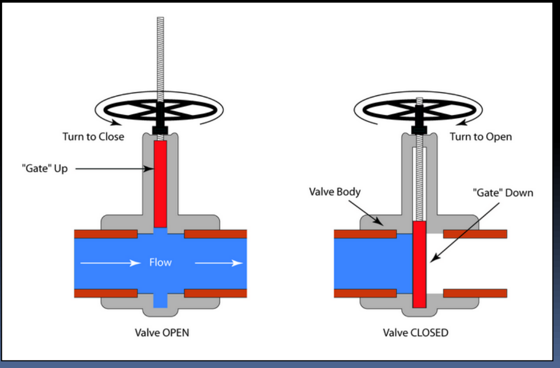
Butterfly valves. City of Banks in Washington Co. Oregon. 2011.

GATE VALVES – ISOLATION OR THROTTLING

GATE VALVES

Gate valves contain a solid gate that is lowered for closing and raised for opening. This gate may be in the form of a square, rectangle, circle, oval, or ellipse. There is very little pressure loss through a gate valve and because they operate slowly, they are unlikely to cause water hammer. In the fully closed position, gate valves provide a positive seal under pressure. However, under very low pressure, i.e. 5 psi, light seepage would not be considered abnormal with this kind of valve. Gate valves should always be left fully open or fully closed. Throttling or fine controlling of gate valves, which places the gate into the flow of the liquid, can cause serious erosion of the gate. Most sedimentation basin inlet valves are gate valves. Gate valves are also commonly used as main raw water intake valves at the heads of water treatment plants.





BALL VALVES - ISOLATION

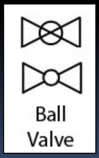
BALL VALVES

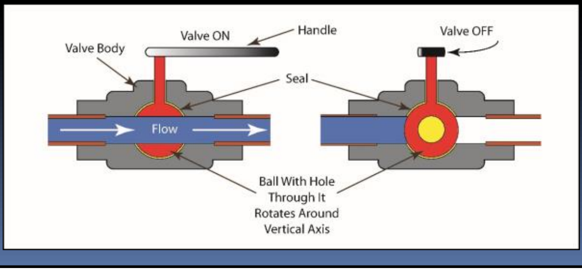
Description - Ball valves are very similar to plug valves, except have a ball-shaped plug with a hole bored through its center that can be rotated to throttle flow. Ball valves are relatively simple and trouble free, have low pressure drops, and open and close quickly, although opening or closing a ball valve too quickly can cause water hammer.

Isolation – Allow quick, quarter turn on-off operation, making them good for isolation. With the development of Teflon seals, ball valves have grown in popularity.

Throttling – Generally have poor throttling characteristics. Ball valves have a ported ball that can be rotated to throttle the flow of clear water, however, they should be operated either fully open or fully closed with any liquid containing particles that could scratch the ball.

Common Uses – They can be used for high or low pressure applications. Most water treatment plant storage tank, day tank, and chemical feed line valves are ball valves.





BUTTERFLY VALVES – ISOLATION OR THROTTLING

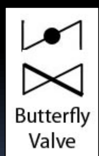
BUTTERFLY VALVES

Description - Butterfly valves, like ball valves, operate with an adjustable circular disc mounted on a shaft in the center of the valve that can be opened or closed with just a 1/4 turn.

Isolation – Not normally rated as bubble tight.

Throttling – Can be used for throttling, but should not be used for throttling for extended periods of time.

Common uses - They are often used for backwash, filter-to-waste, and filter effluent valves. They are generally used for handling large flows of gases or liquids, including slurries. Butterfly valves are also commonly used as large water line valves because they are less expensive than similarly sized ball valves. They are also very compact relative to flanged gate and ball valves.



GLOBE VALVES – PRECISE THROTTLING

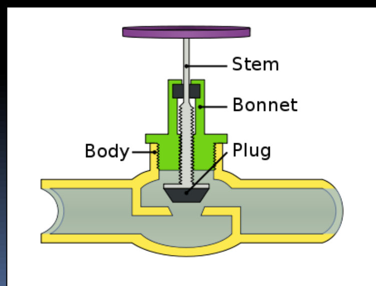
GLOBE VALVES

Description - Globe valves have a casing that historically has been shaped more globe-like than today's models. Globe valves have a plug that fits into a seat within the main cavity area of the globe. Like a gate, globe valves close slowly to prevent fluid hammer.

Isolation – Not typically used for isolation

Throttling - You can throttle the flow and they will not leak under low pressure when they are shut off, but have relatively high head loss.

Common Uses - Flow and pressure control valves as well as hose bibs generally use the globe pattern. The disadvantage of this design is that the "Z" pattern restricts flow more than the gate, ball, or butterfly valves.



PLUG VALVES – ISOLATION OR THROTTLING

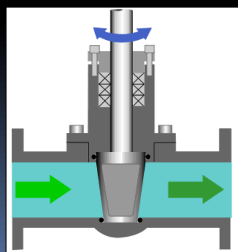
PLUG VALVES

Description - Like the gate valve, a plug valve has an unobstructed flow, yet requires only a 90 degree turn to open it. It also requires very little headroom. Stem corrosion is minimal because there are no screw threads. Almost all plug valves now are furnished with an elastomer-coated plug and will seal off drip-tight.

Isolation – Plug valves can seal well and have a tight shutoff, however, some plug valves are made with a reduced port, which means the valve is smaller than the adjoining pipe's cross-sectional area, leading to higher pressure drop – look for full bore plug valves if you need them.

Throttling – Not typically used for throttling, but they have been used for throttling.

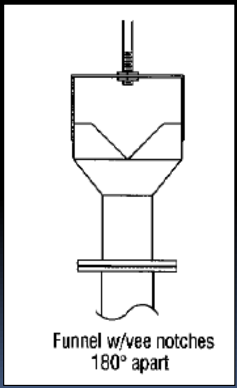
Common Uses - Plug valves are available in much larger sizes than ball valves and are highly suitable for use in wastewater plants.

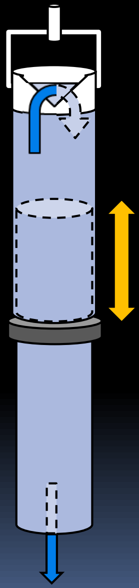


TELESCOPING VALVES

TELESCOPING VALVES

Telescoping valves use a gasketed slip pipe to allow the outlet to be raised or lowered. They can be fitted without weirs or with V-notch weirs.



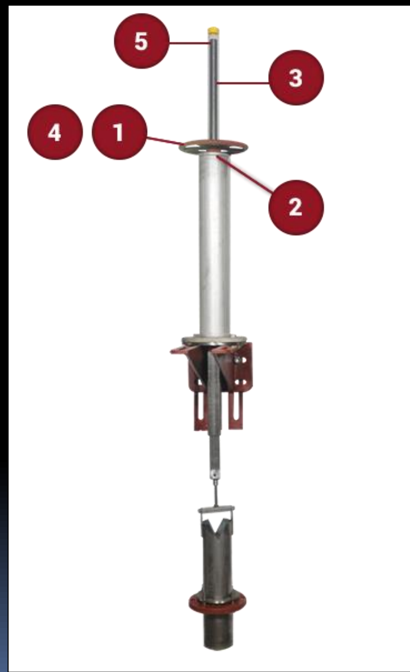


TELESCOPING VALVES

TELESCOPING VALVES

Image to the right shows:

1. Traditional hand wheel
2. Self locking bevel gear
3. Clear acrylic stem cover tube
4. Remote (electric) actuator
5. Valve position indicator



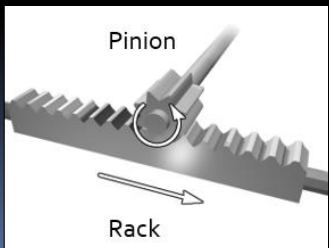
TELESCOPING VALVES

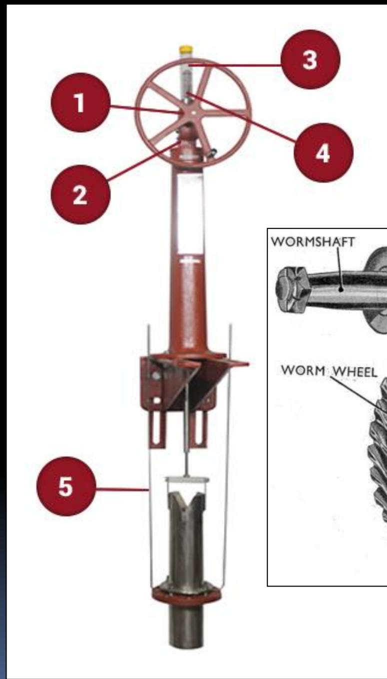
TELESCOPING VALVES

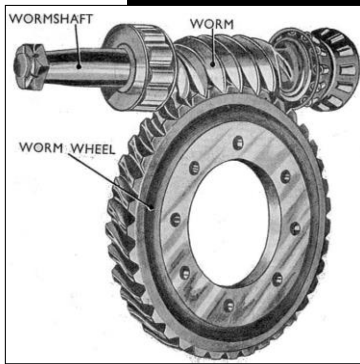
Image to the right shows:

1. Rack and pinion
2. Worm gear box
3. Acrylic rack cover tube
4. Depth indication markings
5. Slip tube lubrication system

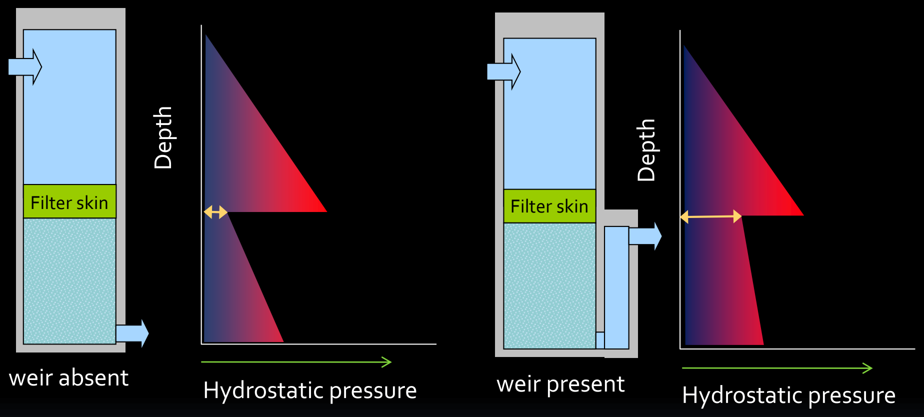
In a work gear, the worm can move the wheel, but the wheel cannot move the worm. In that way the weight of the slip pipe will not turn the hand wheel when released.







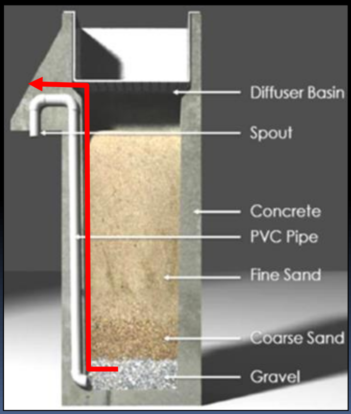
EFFLUENT WEIR



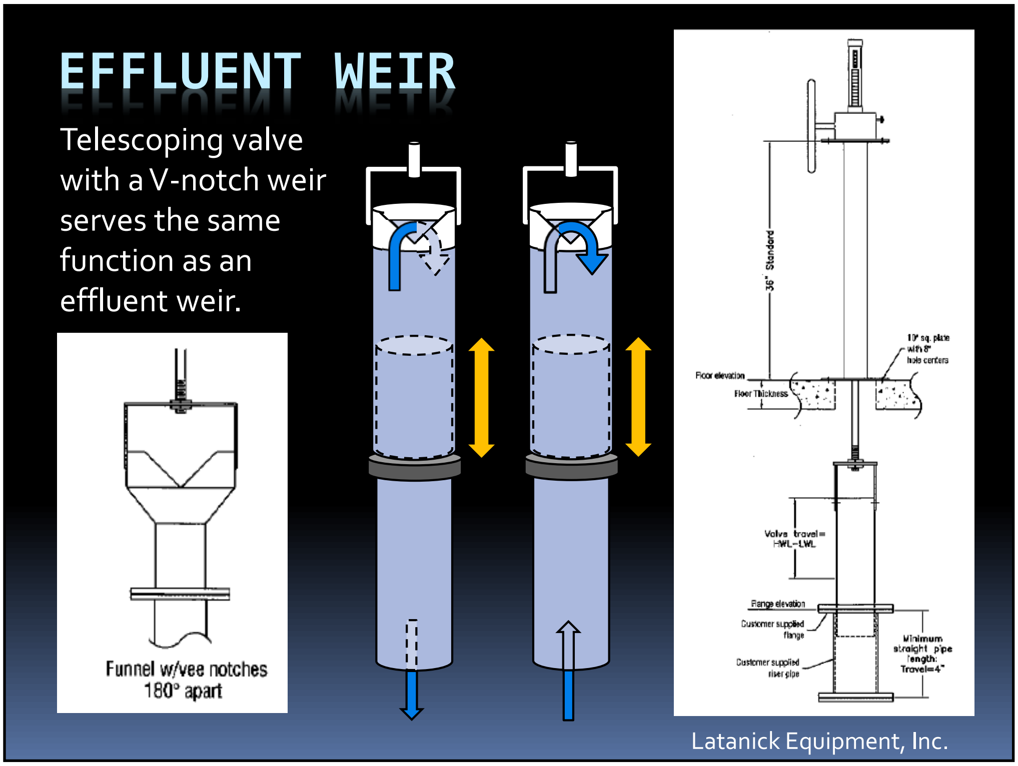
<u>Effluent weir prevents air binding</u> caused by a drop in hydrostatic pressures low enough to cause a partial vacuum in the filter media below the schmutzdecke . This can seriously impact water quality because algal activity causes the supernatant water to become supersaturated with oxygen, which would be released as tiny bubbles in the partial vacuum below the schmutzdecke – the condition known as "air binding". If air binding occurs in a part of the filter, the remaining filter can become overloaded. If air binding is more widespread, the hydrostatic head above the filter can greatly increase, causing a rupture in the schmutzdecke and breakthrough of pathogens.

EFFLUENT WEIR

Effluent piping can be configured to simulate weir in order to prevent unplanned bed dewatering and air binding



BioSand Filter (Dr. David Manz)

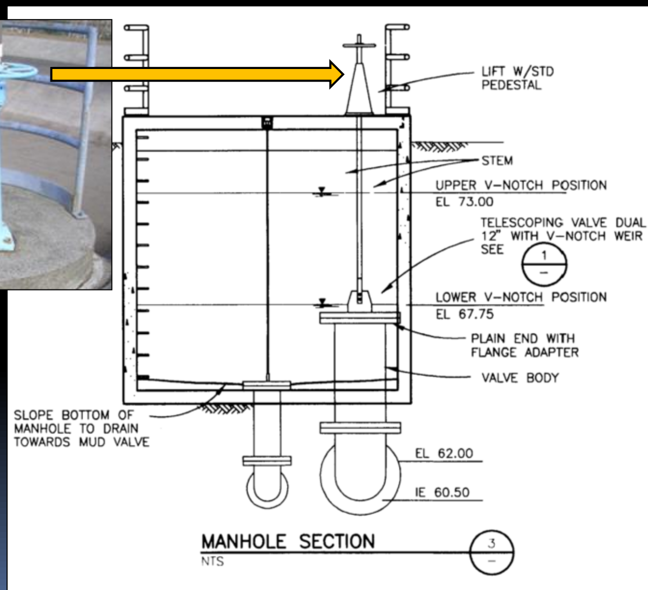


A telescoping valve serves the same function as an effluent weir. Water can either flow over the V-notch weir into or out of the slip pipe.

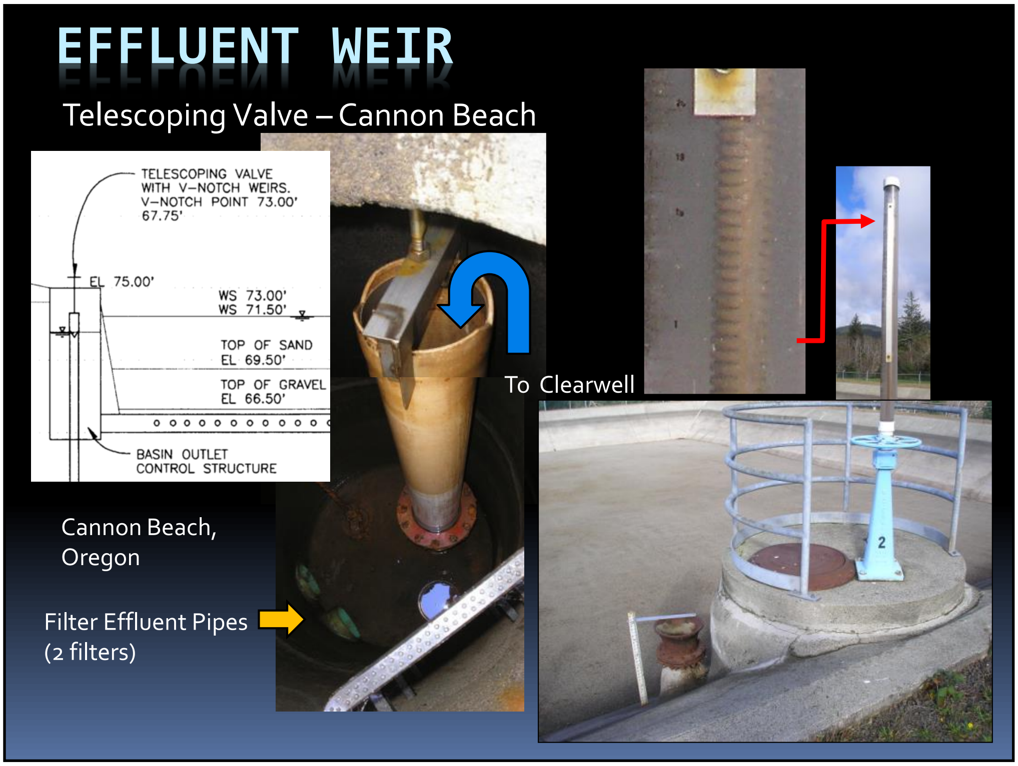
EFFLUENT WEIR

Telescoping Valve – Cannon Beach

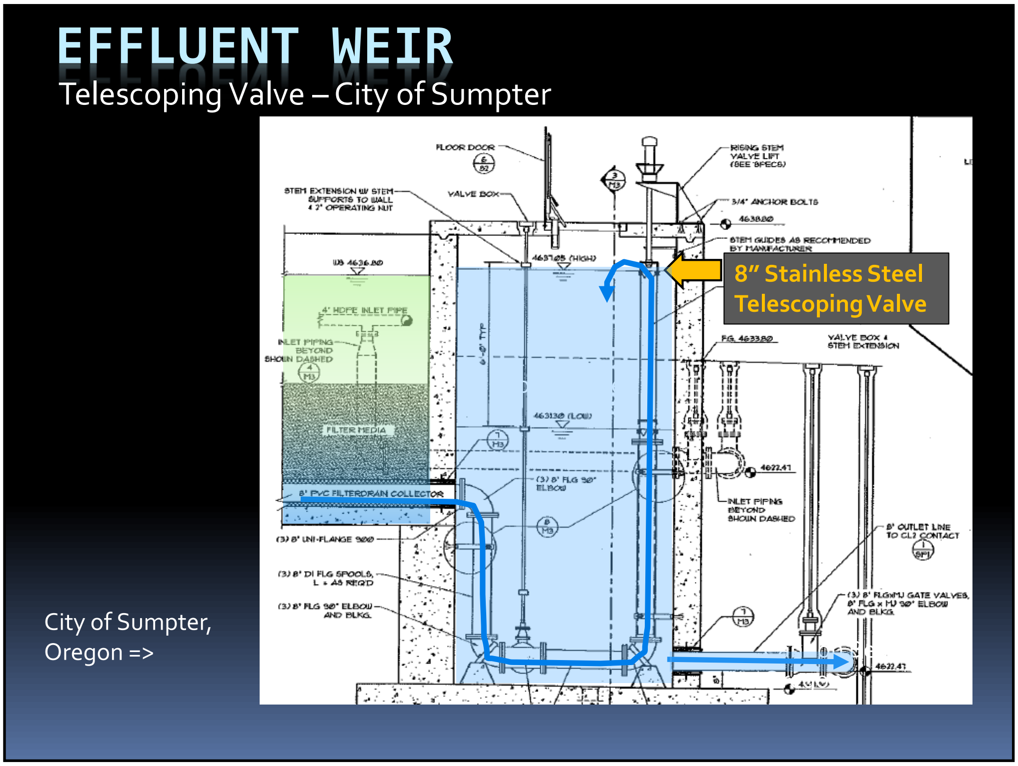
City of Cannon Beach, Oregon



Here is an example of a telescoping valve installed for the City of Cannon Beach, Oregon.



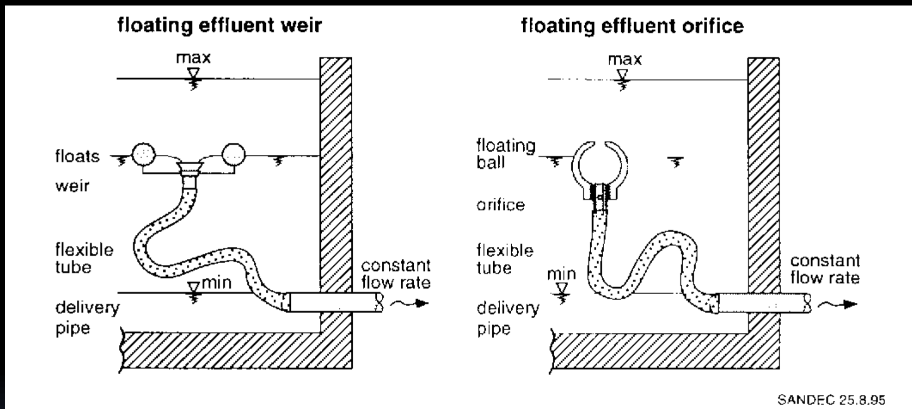
These photos show the interior of the basin outlet control structure with the two filter effluent pipes and the single telescoping valve outlet pipe. A visible site tube allows operators to see and measure the position of the telescoping valve. For Cannon Beach, filtered water flows into the telescoping valve slip pipe and out to the clearwell.



For the City of Sumpter, water flows from the filter underdrain up through the telescoping valve slip pipe and into the control structure.

EFFLUENT WEIR

Floating effluent weirs



These are examples of floating effluent weirs.

TEN STATES STANDARDS
FILTER RIPENING

4.3.4.10 Ripening

Slow sand filters shall be operated to waste after scraping or rebedding during a ripening period until the filter effluent turbidity falls to consistently below the regulated drinking water standard established for the system.

RIPENING NEW FILTERS

Basic steps to ripening a new filter are as follows:

1. Backfill slowly to displace air pockets at a rate of 0.3 – 0.6 feet of filter bed depth per hour (0.0374 – 0.0748 gpm/ft^2) until the inlet jets are covered.
2. Set the weir plate with the crest at the level of influent jets
3. Begin top filing through the inlet jets and begin filtering to waste.
4. The water in the filter box will rise slowly due to the Schmutzdecke buildup and when the level reaches twice the distance between the sand bed and influent jets, lower the weir plate slowly so that the crest is at the level of the sand bed surface.
5. Continue filter-to-waste until the filter is ripened as indicated by turbidity $\leq$ 1 NTU and coliform $\leq$ 10 CFU/100 ml.

FILTER TO WASTE

1. Allows for cleaning newly sanded beds.
2. Allows for ripening without public health risk.
3. Air-gap is recommended to prevent cross-contamination.

DESIGN FOR WET HARROWING

Facilities Needed:

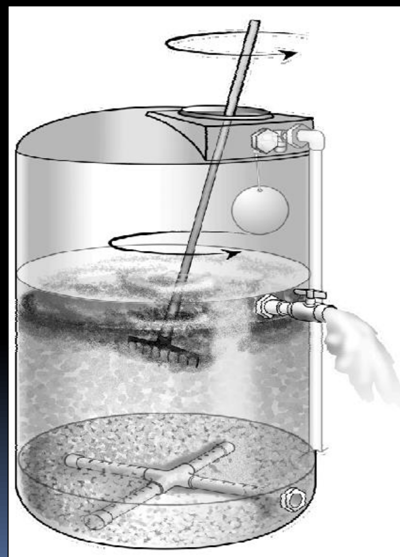
1. Access for harrowing equipment
2. Harrowed water influent distribution system
   - Cross-flow (raw water)
   - Up-flow (filtered water)
3. Harrowed wastewater collection system
4. Holding lagoon for the harrowed wastewater
5. Filter-to-waste piping
6. Provisions to prevent equipment from contaminating filter bed

Facilities needed if designing for harrowing are shown here. Note the additional piping and controls to allow cross-flow of raw water, which is used to flush debris out of the filter bed during harrowing through a waste collection system, as well as up-flow of filtered, but unchlorinated water, to prevent debris from being driven deeper into the sand bed during harrowing.

DESIGN FOR WET HARROWING

Wet Harrowing

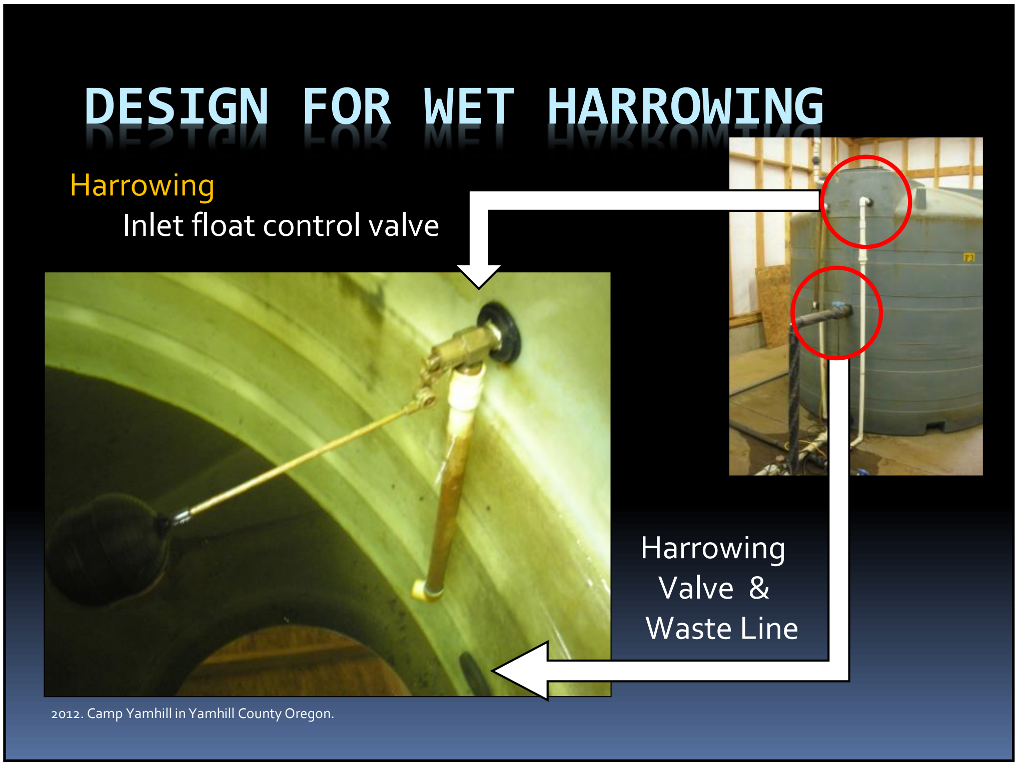
Wet harrowing is a common method of cleaning small filters.



Basic process:

1. Lower water level to ~6” above the top of the sand.
2. Use a rake or rake-like Mechanism
3. agitate top 2”-3” of sand while slowly backflushing with filtered, but unchlorinated water
4. Wastewater is collected through A harrowing valve and waste piping

Wet harrowing is a common method of cleaning small filters. This is often accomplished with just a stiff-tined garden rake. With the water level lowered to about 6” above the sand, the top 2-3 inches of sand is agitated. The material suspended by the raking action is then decanted from the top of the filter through a harrowing valve and waste piping. A slow backflush using filtered (but unchlorinated water) helps keep the suspended material from being driven down into the filter.



This shows the location of the inlet float control valve as well as the harrowing waste line on the inside of the filter. [This photo is also from Camp Yamhill in Yamhill County, Oregon.]

SLOW SAND DESIGN
SCRAPED VS. HARROWING

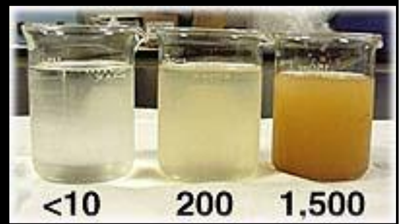
Parameter	Scraped	Harrowed (wet harrowed)
Biomass Development	Biomass and schmutzdecke take longer to develop due to the removal of biomass	Biomass and schmutzdecke restore at a faster rate, however, the sudden release of nutrients can cause dissolved oxygen to dip as microbial grazing intensifies. Keeping influent water flowing and filtering to waste at a higher initial rate can help to replenish depleted oxygen levels.
Removal Efficiency	Equivalent once filter is properly ripened	Equivalent once a filter is properly ripened – usually takes less time to accomplish this.
Filter life	Impacted by removal of top ~2 cm of plugged sand layer	Little media loss leads to longer filter life. Media is more susceptible to deep bed clogging if not done properly.

OTHER DESIGN CONSIDERATIONS

Additional treatment may be needed for challenging waters

<u>Examples:</u>

Roughing Filters (turbidity)
Calcite Contactors (pH)
Ozone (DBP precursors)
Granular activated carbon (TOC/Color)
Filter mat (schmutzdecke removal)
Aeration (low dissolved oxygen)



Michigan Environmental Education Curriculum

City of Astoria, OR
Middle Lake Source 8-28-13
Photo by Gary McLauchlin
Aphanizomenon flos-aquae

Challenging source waters may require additional treatment. For example, roughing filters may be used prior to slow sand filtration to combat high turbidity, calcite contactors may be used after filtration to increase pH with corrosive waters, and ozone prior to filtration may be needed to address DBP precursors. These processes may all be piloted if needed.

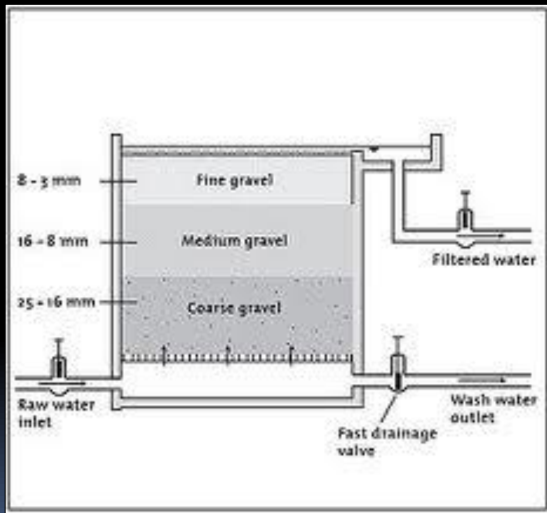
OTHER – ROUGHING FILTERS

Roughing Filters

Indicated with pilot test results.

May be required in the future due to changes In source water quality.

Pre-planning ensures flexibility



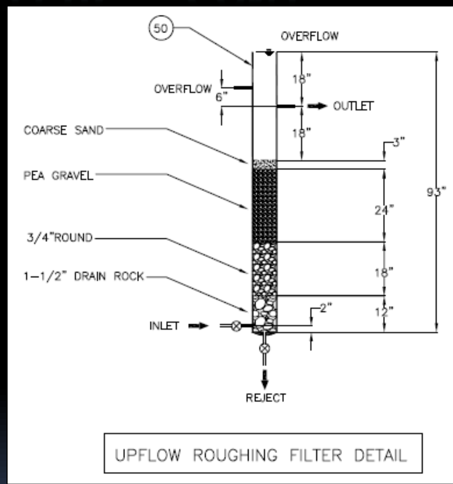
Pilot testing may reveal that roughing filters are needed. Changes to water quality over time also may dictate the need for roughing filters at a future date. Pre-planning ensures this flexibility.

ROUGHING FILTERS, CONT.

Roughing Filters

Reduces the algae and sediment load to the filters

As with slow sand filters, biological maturity is key to optimal performance



Effectiveness

90% removal of particles > 10 microns (medium silt and larger)
72% removal of 2-5 micron particles (Cryptosporidium size particles)

Roughing filters can be 90% effective in removing particles larger than 10 microns and 72% effective at removing particles in the 2-5 micron size range. This diagram shows the basic elements of a roughing filter, with the gradual gradation of larger and larger size media.

ROUGHING FILTERS, CONT.

Roughing Filters

- Can be upflow, downflow, or horizontal
- Filtration rates of 0.12 – 0.62 gpm/ft^2
- Cleaned by flushing at high hydraulic rates. Hydraulic surges can be generated by rapid openings and closings of the inlet and outlet valves
- Horizontal flow roughing filters are considered to have greater silt storage capacity and lower hydraulic cleaning needs than upflow or downflow roughing filters.

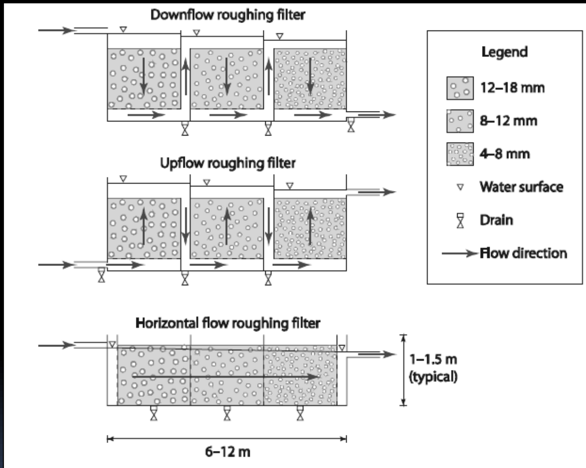


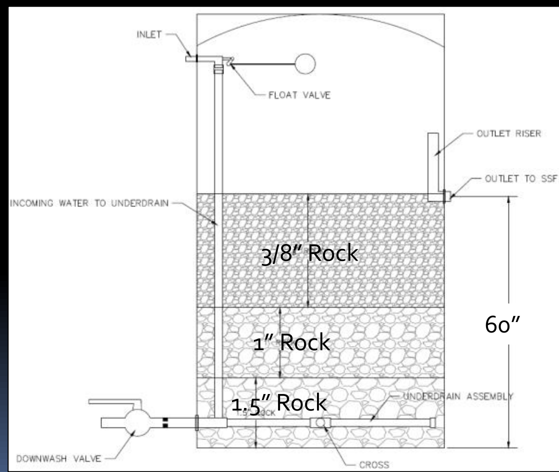
Figure 2.1 Typical roughing filter configurations (Collins et al., 1994)

Roughing filters can be upflow, downflow, or horizontal in configuration with filtration rates of 0.12 – 0.62 gpm/ft^2. They are cleaned by flushing at high hydraulic rates, sometimes generated by the rapid opening and closing of inlet and outlet valves.

ROUGHING FILTERS, CONT.

Roughing Filters

- Gravel size range from 0.2 – 2 in.



Calcite contactors like this limestone contactor can help increase the pH in corrosive waters.

OTHER - OZONE

Ozone

- Used prior to or after filtration for organics removal (DBP precursors)
- Oxidizes iron and manganese
- Reduces some algal toxins
- Removes color, taste, and odor causing compounds
- Increased O&M due to shorter filter runs

Large water system ozone

Not commonly used in conjunction with slow sand filters in the Northwest is the use of ozone. Ozone is an effective means of addressing DBP pre-cursors as well as high iron and manganese. The use of ozone may lead to shorter filter runs and, hence, more frequent filter cleaning.

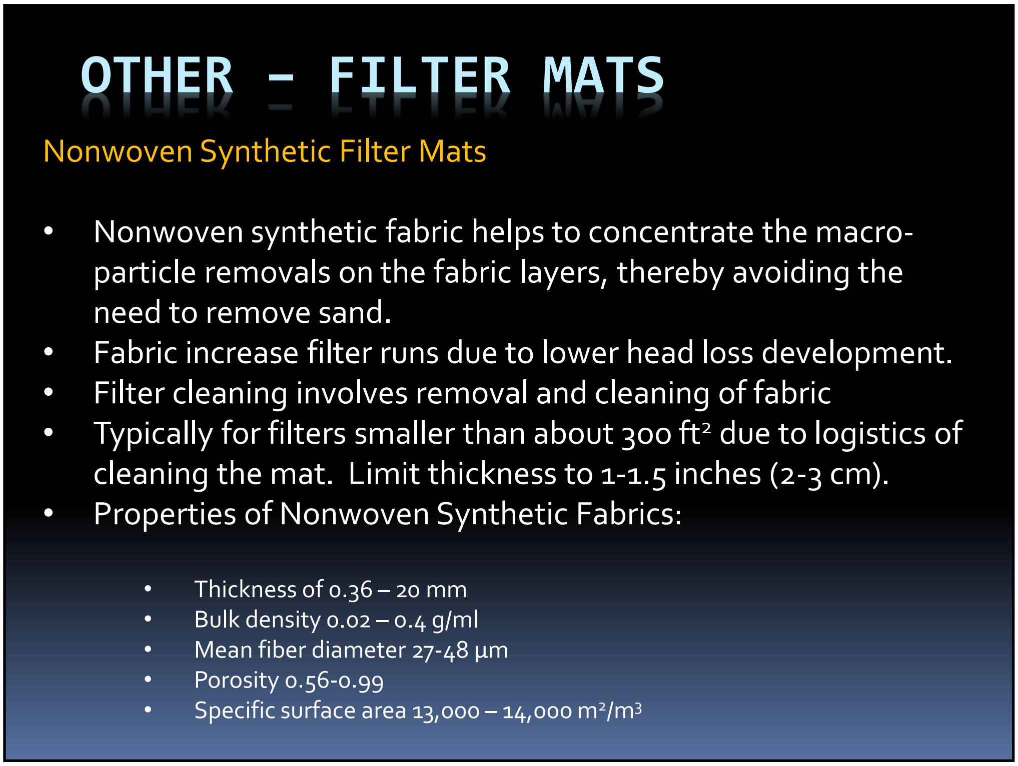
OTHER – ACTIVATED CARBON

Granular Activated Carbon

- Removes color, taste, and odor causing compounds.
- Needs to be replaced when depleted (i.e., deactivated)

Comparison of Slow Sand with and without a layer of GAC		
Parameter	**SSF w/out GAC**	**SSF with GAC**
Cleaning Frequency	30 days	No change
Color Removal	20%	50%
TOC reduction	20%	35-40%
TTHM Formation Potential Reduction (24-hr contact time)	130 µg/L	60 g/L

Also not commonly used in conjunction with slow sand filters in the Northwest is the use of GAC.



Although not common, nonwoven synthetic fabrics may be used to assist with cleaning while minimizing sand removal. It does this by trapping macro particulate matter in the mat rather than the sand, which means that you do not have to scrape the sand to restore headloss.

OTHER – AERATION

Aeration

May be needed if DO < 6 mg/l

May be required in the future due to changes in source water quality.

Pre-planning ensures flexibility

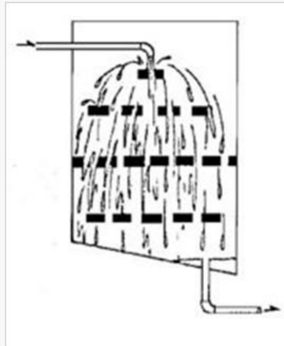
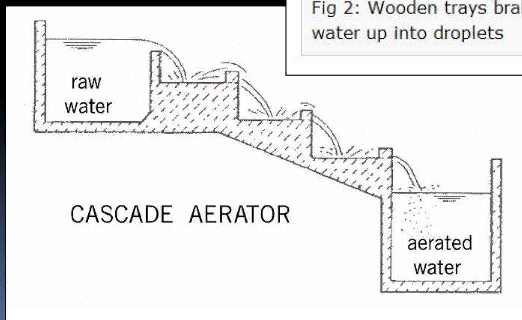


Fig 2: Wooden trays brake water up into droplets



Pilot testing may reveal that aeration is needed. Changes to water quality over time also may dictate the need for aeration at a future date. Pre-planning ensures this flexibility.

MONITORING POINTS

The recommended minimum location points for recording and monitoring include:

Source water for:

- Turbidity
- Flow
- Temperature
- pH
- Grab sampling of coliform, TOC, or other water quality parameters

Supernatant for:

- Level
- Headloss
- Grab sampling of coliform, TOC, or other water quality parameters

It is important to account for monitoring requirements as part of the design process. This ensures that sample taps and flow monitoring is adequate to support operations.

MONITORING

Individual filter effluent for:
- Flow rate and quantity
- Turbidity
- Grab sampling of coliform, TOC, or other water quality parameters

Combined filter effluent for:
- Flow rate and quantity
- Turbidity
- Grab sampling of coliform, TOC, or other water quality parameters

Finished water (post disinfection and storage used for disinfection contact time) for:

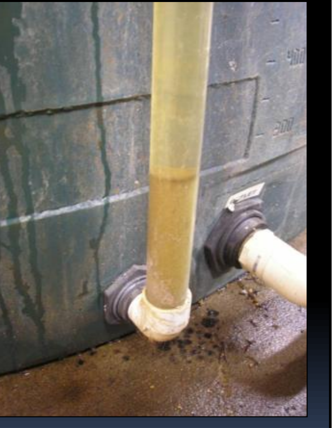
- Flow rate and quantity
- pH
- Temperature
- Chlorine residual
- Grab sampling of coliform, TOC, or other water quality parameters

Finished water storage for:
- Effluent flows
- Level

MONITORING HEAD LOSS

Head loss Measurement

On smaller facilities, routine visual observation of the supernatant depth and recording of the flow rate may be sufficient to monitor filter head loss development.



On larger facilities, screened probes at the top and bottom of the filter sand can allow easy measurement of head loss with simple piezometers mounted outside the filter, or through the use of a differential pressure transducer connected to the facility's SCADA system.

Tracking this data will allow the operator to predict and plan filter cleanings.

O&M MANUAL

Frequency and tasks are adapted from WHO, 1996. *Fact Sheets on Environmental Sanitation, Fact Sheet 2.12: Slow Sand Filtration*

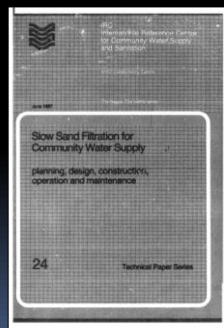
Frequency	Labor (person hours)	Slow Sand Filter Maintenance Task
Daily	1 - 3	Check raw water intake Check/adjust filtration rate Check water level in filter Check water level in clear well Sample & check water quality (raw/finished NTU, raw temp) Check pumps Enter observations in logbook
Weekly	1 - 3	Check & grease any pumps & moving parts Check/re-stock fuel Sample & check water quality (coliform) Enter observations in logbook
1 – 2 months	5 / 1,000 ft2 50 / 1,000 ft2 /12 inches of sand for re-sanding (Letterman & Cullen, 1985)	Scrape filter beds Wash scrapings & store retained sand Check & record sand bed depth Enter observations in logbook

Design should include development of an Operation and Maintenance Manual. Some of the tasks that should be included are shown here. More about this will be discussed later as we get into operations.

KEY REFERENCES – 1974, 1987

1. "Slow Sand Filtration", World Health Organization (Huisman & Wood), 1974;
2. "Slow Sand Filtration for Community Water Supply", International Research Center for Community Water Supply and Sanitation (Visscher et al., 1987)

http://www.who.int/water_sanitation_health/publications/ssf/en/index.html



http://www.irc.nl/page/4530

Again, the key references are shown here.

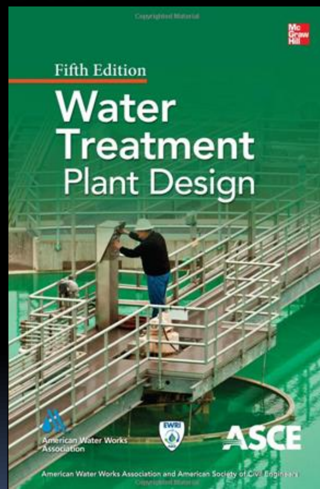
KEY REFERENCES - 1991

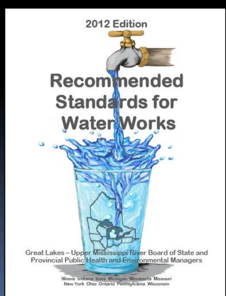
"Manual of Design for Slow Sand Filtration" . David Hendricks & American Water Works Association, 1991. ISBN 978-0898675511

The "Manual of Design for Slow Sand Filtration" covers design in great detail.

KEY REFERENCES - 2012

"Water Treatment Plant Design, 5^{th} Edition". Stephen J. Randtke, Ph.D., P.E.; Michael B. Horsley, P.E. Co-published by the American Water Works Association; Environmental and Water Resources Institute of American Society of Civil Engineers; McGraw-Hill Professional. 2012. ISBN: 9780071745727





Recommended Standards for Water Works (a.k.a., "Ten States Standards", 2012);

http://10statesstandards.com/

Here is a more recent publication, which covers design as well.

QUESTIONS ABOUT DESIGN?