REHABILITATING WATER FILTER SYSTEMS WITH POTENTIAL CUBA APPLICATIONS

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The nation of Cuba derives its drinking water from both surface water and groundwater sources. Usually treatment for groundwater sources is chlorination with no further treatment. Cueto, et al estimate there are 59 surface water treatment plants that use a combination of American, European, Soviet and Cuban designs. Many use conventional treatment processes which consist of chemical addition, flash mixing, coagulation, clarification, filtration, and disinfection. Some may use direct filtration, which would consist of chemical addition, flash mixing, coagulation, filtration and disinfection. This paper will look at the rehabilitation of existing gravity, granular media filtration systems using the dual parallel lateral underdrain design along with updating other aspects of gravity filtration systems that could be used in Cuba to upgrade its water treatment systems. The paper concludes with illustrative costs based on other gravity filter rehabilitation that has been recently done in the Latin American region.

GRAVITY FILTRATION

Gravity filtration in water treatment is the passage of water through a porous, granular medium for the physical removal of suspended solids and turbidity. If conditions are proper, biological growth within the medium can remove other contaminants. The earliest written records of water treatment, dating from about 4000 BC, mention filtration of water through charcoal or sand and gravel. Although a number of modifications have been in the manner of application, filtration remains one of the fundamental process technologies associated with water treatment.

Granular filter media (effective sizes ranging from 0.5-1.5 mm) will generally remove particles that are larger than 7-10% of the smallest media grains. Most water treatment applications try to remove color and all solids greater than 10-20 microns. Smaller particles are removed using chemicals to destabilize colloidal dispersions and enhance the growth or coagulation of particles into a size that can be removed. For additional biological treatment other chemistry can be added as a food source for the biology.

In gravity filters, the conditioned raw water is introduced into the top of a basin, flows down through the selected media bed, and is collected by the underdrain system as shown in Figure 1. The driving force through the system is the distance from the water level over the filter to the first air break which is usually into a clearwell or control weir. As solids are accumulated and/or biology grows in the filter media, the headloss or force required to maintain flow increases. A point is reached where either the flow cannot be maintained or solids are driven through the filter. An upward flow of water or a combination of air and water (called a backwash) is used to scour and fluidize the media thereby removing the accumulated particles with some of the biology and restoring the driving force. The effectiveness of a backwash operation is measured by the resulting cleanliness of the media and the associated costs of power and water required to perform the backwash.

The current best practice backwash is to begin with an air scour to agitate the media surface, followed by an air scour with low rate water backwash in the "col-

Figure 1.   Typical Gravity Filter System
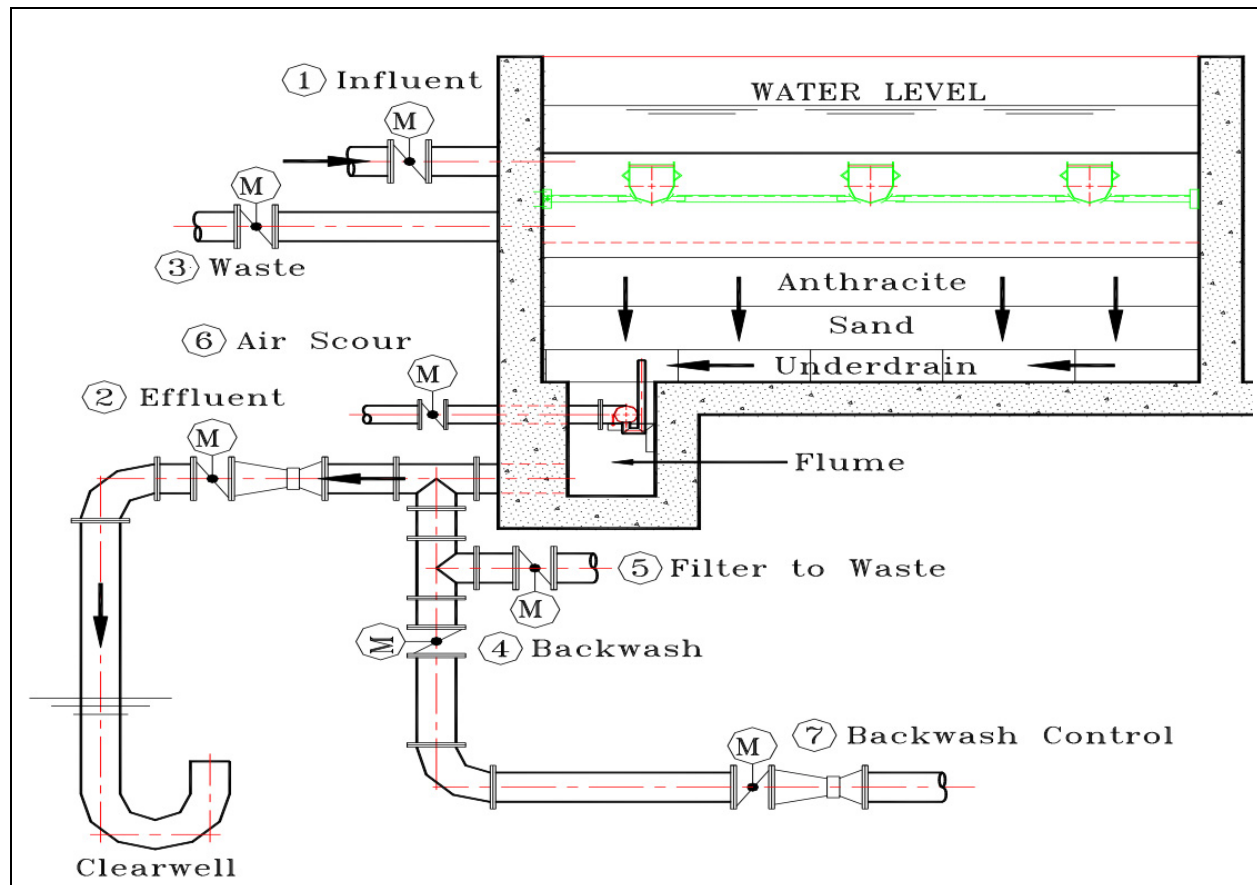
lapse-pulse" manner to agitate the whole bed, and finally a high rate water-only backwash to expand the media and remove particles from the media bed. Several studies have shown that the air/water backwash regime provides a cleaner media using less backwash water. Amirthirajah et al. have shown that a backwash in the collapse-pulse region cleans dual media and granular activated carbon the best. Collapse-pulse is defined as the combination of air and water that allows the air to compress and expand as it passes through the bed. Achieving a collapse-pulse condition therefore will give the optimum filter wash and should be used in the design of most backwash system.

SINGLE-PASS UNDERDRAIN SYSTEMS

The purpose of the underdrain system in a gravity filter during the filtering mode is to support the media, collect the treated water, and channel it to the discharge piping to the clearwell. When the filter media becomes dirty, the underdrain is used to evenly dis-

tribute the backwash water and air used to flush out the accumulated particles. The backwash mode is where the underdrain is most critical. If the backwash water and air are not evenly distributed, dirt can accumulate within the filter media causing uneven forward and backwash flows. Over time as the dirt accumulates in the media, usually in the form of mudballs, the filter run-time or time between backwashes and particle removal performance deteriorates. Uniform backwash distribution is critical in maintaining the long-term performance of rapid gravity filters.

There are two basic types of underdrain systems in general use: single pass systems and dual-pass systems. Examples of single pass underdrain systems are pipe laterals, nozzle/strainers, Wheeler systems, Tee Pees or folded plates, etc., shown in Figure 2. The flow distribution of these types of single pass underdrain systems is dependent upon a single series of orifices contained within the underdrain. In order to
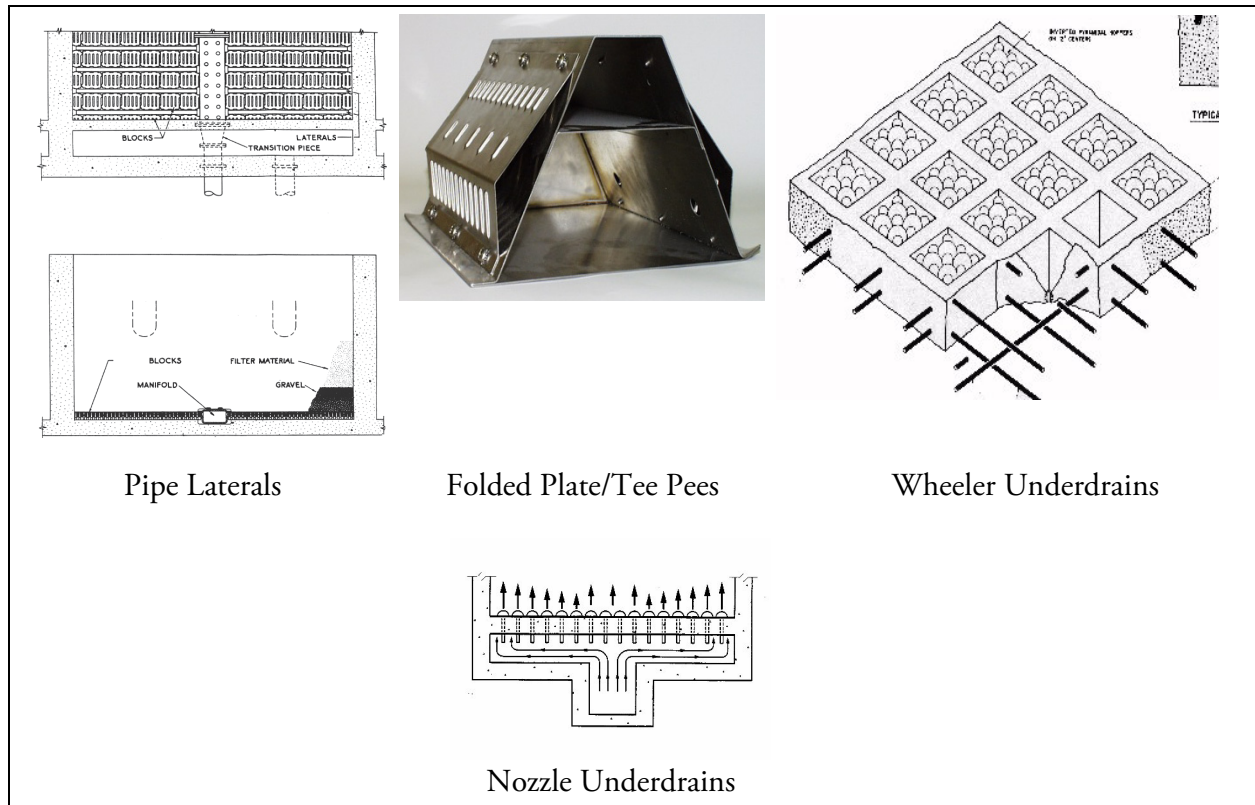
Figure 2. Single Pass Underdrains

Pipe Laterals Folded Plate/Tee Pees Wheeler Underdrains

Nozzle Underdrains

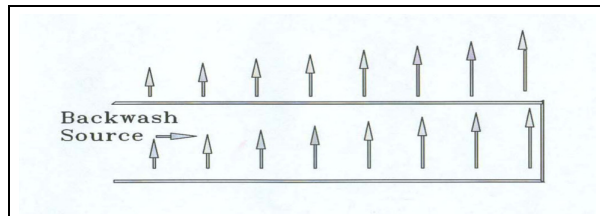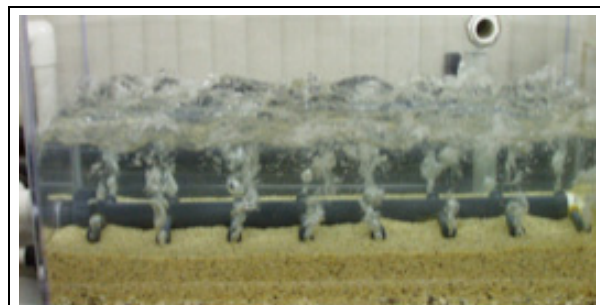**Figure 3. Flow Distribution in a Single Pass Lateral**

**Figure 4. Air Distribution of a Pipe Lateral System**

maintain an even distribution of flow, the lateral lengths must be kept to a minimum or in the case of the nozzle/strainers, the plenum must be made deep. A deeper plenum adds significant additional initial construction costs.

Figure 3 shows the distribution of backwash water in a single pass underdrain system. The flow velocity is the highest at the inlet area and the water tends to pass the first few orifices. As the flow proceeds through the lateral with velocity and quantity decreasing, more flow proceeds through the orifices at the end of the lateral. Because of this inherent characteristic of single pass laterals, the lateral lengths are best kept less than 10 feet (3 meters).

Some of these single-pass systems, such as the pipe laterals, concrete Tee Pees and Wheeler type underdrains, are not conducive to adding an air wash. An air wash system may be added using a pipe lateral system over or between the laterals. However the spacing of the orifice openings is usually 6 to 8 inches (15-20 cm), which provides a channeling effect that is very inefficient. as shown in Figure 4. Figure 4 shows a Perspex (Plexiglas) model that contains a pipe lateral system with openings on about 15 cm (6 inch) cen-

Figure 5. Nozzles During Air Scour
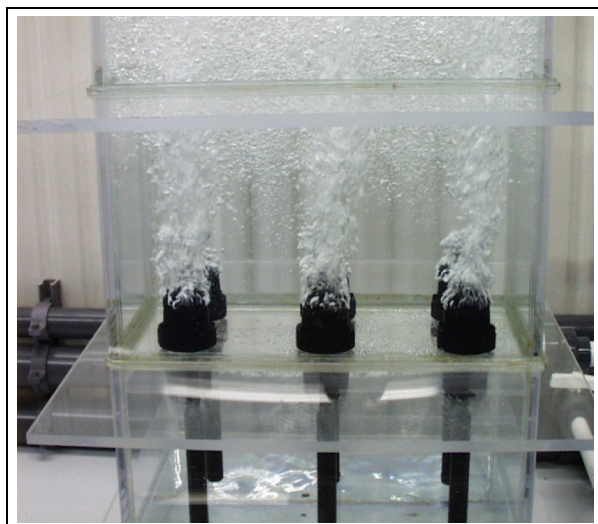
Figure 6. Dead Zone Effect from Nozzles
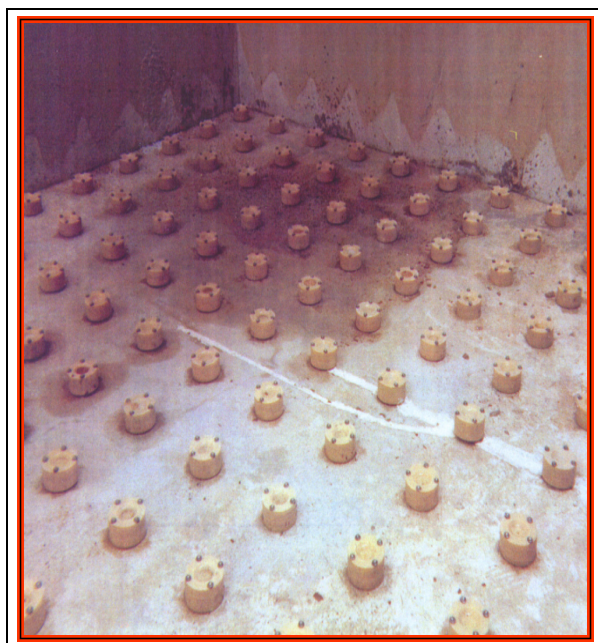
ters. Not only is the channeling evident but this air lateral system is located above the support gravel. Besides not cleaning the gravel, the underdrain does not benefit from air scour cleaning.

Nozzle/strainer systems can be retrofitted with air scour. Figure 5 shows a Perspex (Plexiglas) model with nozzles in the air backwash mode. The nozzles are at 15 cm (6 inch) x 20 cm (8 inch) centers. Note the channeling effect of the air as it rises out of the top of the nozzle. The area immediately between the

nozzles and above for about 15 cm (6 inches) does not benefit from the air scour. When inspecting this type of underdrain from the top it appears that there is uniform coverage of air. However viewed from the side, the channeling is evident. This channeling provides an area for the deposition of solids. During replacement of these types of underdrains, it has been observed that the filter walls are stained with dirt deposits as shown in Figure 6. The dead zone is evidence that air and water are not cleaning the media at the lower levels.
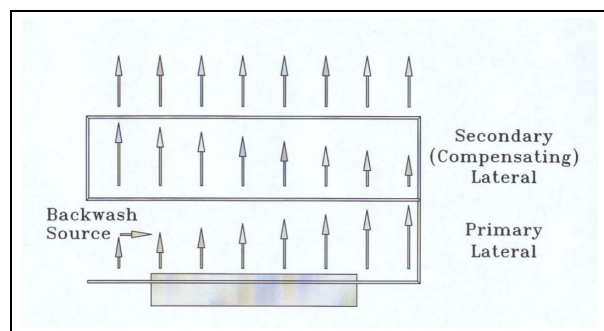
THE DUAL-PARALLEL LATERAL

The dual parallel lateral was developed to solve the flow distribution problems of other systems. As shown in Figure 7, it consists of a primary lateral and two secondary compensating laterals which are parallel to each other. Control orifices open from the primary lateral directly into the secondary laterals. Backwash water is introduced into and flows through the primary lateral, rises and discharges from the control orifices into the secondary compensating lateral. Any unbalanced flow from the primary lateral creates an opposing flow, forming a directly compensating velocity pressure gradient which puts the secondary lateral into a uniform hydraulic pressure condition throughout its length as shown in Figure 8. This uniform pressure services the top deck dispersion orifices that discharge from the compensating lateral into the filter box.

Hydraulics dictates that, neglecting friction, the amount of water that will flow from a lateral through a particular orifice is a function of the orifice coefficient and the hydraulic gradient in the lateral at the entry to the orifice. In a lateral having equal sized and shape orifices along its length, the orifice furthest form the point of admittance will deliver the most water. These discharge variances exist in the primary lateral of the dual parallel lateral underdrain, as in any single-pass lateral system as shown in Figure 3. The function of the secondary/compensating laterals is to provide a compensation or balance to these variances. This system provides an automatic equalization of pressure prior to discharging the backwash water from the underdrain, resulting in complete uniform discharge along the entire length of the lat-
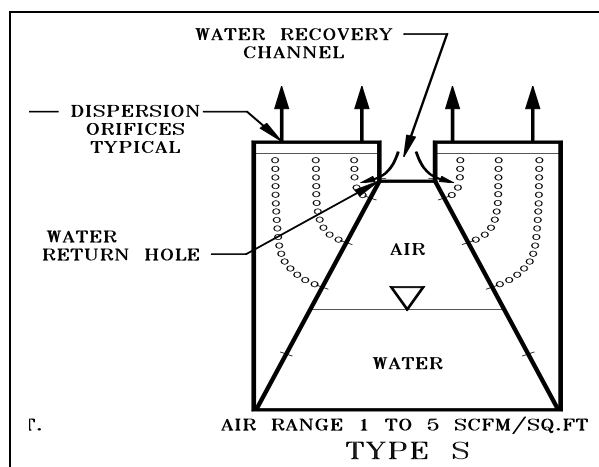
Figure 7.   Dual Parallel Lateral Underdrain

Figure 8.   Flow Distribution in a Dual Pass Lateral Showing the Effect of the Compensating lateral

Figure 9.   Air Dispersion in the Dual Parallel Lateral Underdrain

eral. Dual parallel laterals can be sized up to 15 m (50 feet) in length with a backwash lateral mal-distribution of less than ±2%. Mal-distribution is the percent difference in flow from one part of a lateral or underdrain system to another. Usually the highest and lowest points of flow or pressure are used to determine mal-distribution.

An additional benefit of the dual-parallel lateral is its unique ability to meter and uniformly distribute air. Widely spaced nozzles, such as those used in single pass systems, release large volumes of air creating disruptive "explosions" propelling media to the surface and providing zones of low or no turbulence. The triangular shape of the primary lateral collects incoming air uniformly along its length. Small dispersion orifices as shown in Figure 9, then distribute and meter the air uniformly to the top deck discharge orifices. The top deck orifices are closely spaced at 5 cm (2 inch) centers to provide a more uniform coverage of the filter floor. A baffle in the bell end of the second-

ary laterals ensures that the air and water that are metered into each 1.2 m (4 feet) section are discharged from that section. Without the baffle, the backwash water tends to push the air up and down the lateral causing pulsations.

The latest developments in the dual parallel lateral underdrain design are the arched primary conduit, dual water recovery channels, water baffles in the secondary and a grout pocket on the bottom of the underdrain. The arched primary allows more air and water to flow through the underdrain which in turn allows for up to 40% longer lateral lengths than the previous low profile underdrain. This means that the low profile underdrain can be used in larger filters. The dual water recovery channels allow more uniform air distribution through the top deck orifices during air scour. The water baffles on the arch wall

reduce secondary velocities and provide extra crush strength. The grout pocket on the bottom of the underdrain provides up to 3 times the resistance to internal uplift pressure than the older underdrain designs. Sometimes pressure transients are caused in the backwash system. The grout pocket provides additional insurance against these unexpected pressure transients. All of these new developments add up to the latest in gravity, granular filter underdrain design.

INSTALLATION OF THE DUAL PARALLEL LATERAL

The installation of the dual parallel lateral is very simple. The filter compartment is constructed like a box with a rough-finished, plain flat floor. The design does not require any special sub-structure, such as supporting piers or beams, nor does it require added filter depth for a plenum or false floor. The 1.2 m (4') dual parallel lateral blocks are set in a base grout directly on the flat filter floor with minimum anchorage required.

The dual parallel lateral blocks are placed end-to-end in rows so the laterals are continuous through the length of each row. Rows of blocks are placed on ± 30.5 cm (12 inch) centers across the width of filter. The space between the rows is filled with grout, locking the blocks together and making a flat and level tile floor that is an integral part of the filter box.

Figure 1 shows the typical installation of the dual parallel lateral in a filter with a front flume. The backwash water enters the flume, travels into the dual parallel laterals, is dispersed up into the media, and finally is collected by fiberglass washwater troughs. Note the air header piping in the flume that uses "j-risers" to distribute the air to each dual parallel lateral. The air riser "j" shape is used to flush any water that accumulates in the bottom of the air header piping as the air fills the header.

MEDIA EFFECTS ON BACKWASH DISTRIBUTION

Underdrain systems can be designed to produce low mal-distribution within the filter box and in some cases with low overall headloss. However, the installation of media adds another factor to be considered.

Figure 10. Media Headloss Controls Backwash Flow until the Underdrain Headloss Exceeds the Media Headloss
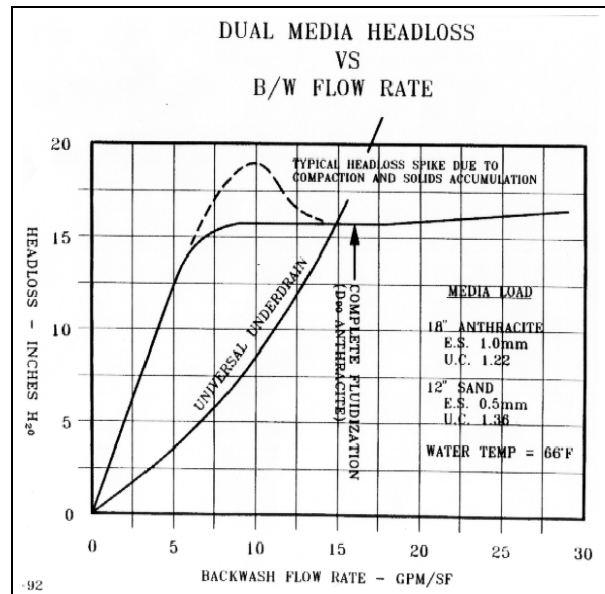
Flow distribution is headloss driven. A headloss differential is required for one component to control another. Some underdrain manufacturers claim they can produce good mal-distribution with low headloss. If piping and distribution elements are sized properly, low mal-distribution can be achieved with a bare underdrain. However, if the media headloss is higher than that of the underdrain in the backwash mode, mal-distribution can occur. When the media is dirty, an even higher pressure is required to loosen and fluidize the media bed.

As the backwash rate is increased, a headloss spike occurs at the point of incipient media fluidization due to compaction and solids accumulation. During this period, the media will have significantly higher headloss than the underdrain as shown in Figure 10. The distribution provided by the underdrain may not be adequate to clean the bed uniformly. As the bed goes into fluidization, localized regions become zones of lower headloss accentuating mal-distribution beyond that expected for the underdrain. The media will then be controlling backwash distribution, not the underdrain. The media can then contribute to the mal-distribution in the filter.

Figure 11. Typical Rehabilitation of a Single Pass, Plenum Type Filter
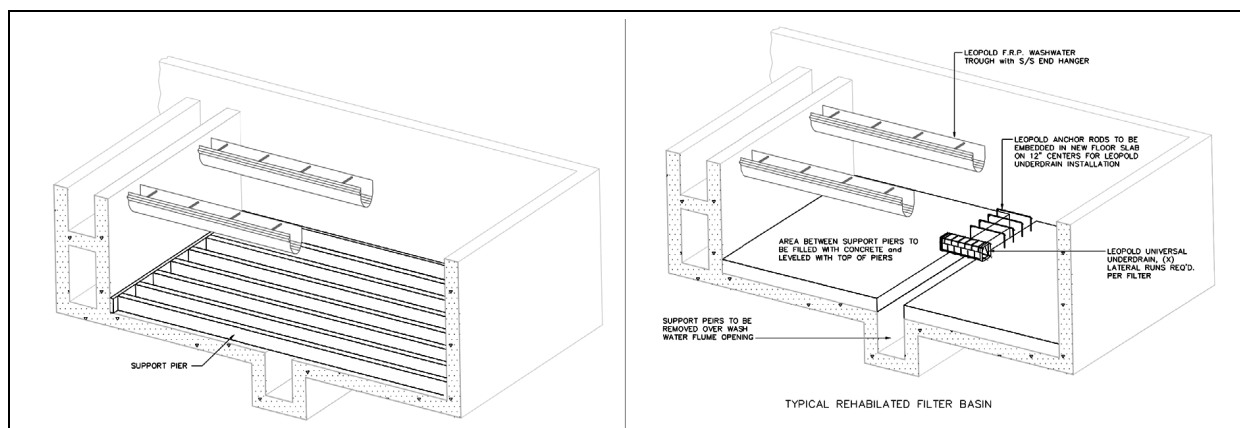
Two important conclusions can be drawn: the underdrain headloss should be higher than that of the media at the design backwash flow rate and air scour should be used to help prevent the build-up of solids in the media.

REHABILITATING EXISTING UNDERDRAINS USING THE DUAL-PARALLEL LATERAL

When rehabilitating an existing filter system, such as those that exist in Cuba, many factors must be considered. These factors include an adequate backwash flow based on the existing backwash system, configuration of the backwash flume, depth and shape of the filter box, and characteristics of the proposed media. The backwash flow rate is dependent on the type of media to be used. If using a dual media, the backwash flow rate should be adequate to fluidize the large particles of the media, usually the anthracite depending on the specific gravity and particle sizes used. During an air scour, the sand and anthracite are mixed together. Adequate fluidization is required to flush the accumulated solids from the filter as well as separate the sand from the anthracite. The usual design backwash flow rate for a standard dual media is 49 m/h (20 gpm/sf) at 21° C (70° F).

The configuration of the backwash flume is very important as it is one of the major contributors of maldistribution in a filter along with the underdrain lateral type and the media as discussed before. If a backwash flume does not exist, one needs to be constructed on the floor of the filter. Figure 11 shows the progression of removing the floor of a nozzle/strainer

or Wheeler underdrain system and filling between the dwarf walls to form a flume. The dual parallel lateral is placed perpendicular to the flume and the backwash water is introduced into the bottom of the underdrain through cut-outs in the block. Air can also be introduced to the bottom of the underdrain using j-risers similar to the ones shown in Figure 1. The flume is designed so that the equalized flow velocity is 2 km/h (2 fps) or less and the backwash entry pipe velocity is 4 km/h (4 fps) or less. If the entrance velocity is too great, baffling is provided to dissipate the entrance energy and allow the flow to equally enter all of the laterals.

Figure 12 shows the arrangement used to rehabilitate a pipe lateral type of underdrain. A layer of fill grout is placed on the floor and the flume block is cut-out to add additional flume area. In this case the flume was not large enough to accommodate the air header piping so the air was introduced overhead with drop pipes to the primary lateral.

The configuration of the filter box in a filter rehabilitation will influence many decisions. First it will determine the length of the dual parallel laterals. The location of the backwash entry will determine the location of the flume such as a front flume or a center flume or no flume and possibly the size of the flume. The length of the lateral will determine the type of block. Low profile dual-parallel lateral blocks with a height of 20 cm (8 inch) have been developed for shallow depth filter boxes (See Figure 7). But for an air/water backwash, the lateral length of the low profile block is limited to 5.5 m (18 feet) from the back-

Figure 12. Arrangement to Rehabilitate a Pipe Lateral Underdrain Using Overhead Air Piping
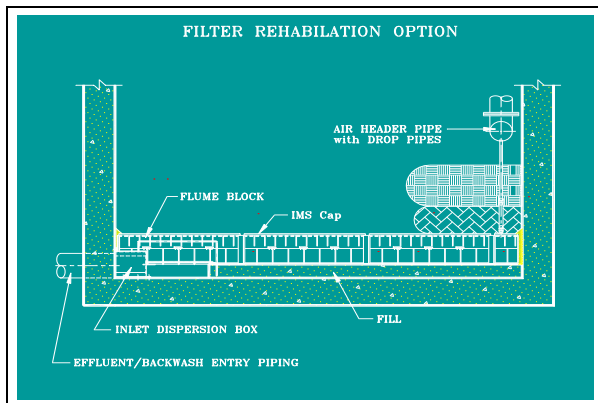
wash source. That is 5.5 m (18 feet) for a front flume filter as shown in Figures 1 and 11 m (36 feet) for a center flume filter as shown in Figure 11. For lateral lengths up to 15.2 m (50 feet) from the backwash source, the high profile block is used which has a height of 30.5 cm (12 inches). This is also where a trade-off may have to be made with media depth in order to fit all of the equipment into the box. The usable depth of the filter box is determined from the maximum elevation between the backwash inlet and the backwash outlet. In this depth, the designer must fit the backwash flume, the dual-parallel lateral underdrain, the media support, the media, and sufficient freeboard to the backwash outlet to prevent media loss.

Another development for adding media depth or increasing freeboard into an existing filter box is the use of a gravel-less support plate (See Figure 7) in lieu of graded gravel. The use of a 2.5 cm (1 inch) gravel-less plate adds 28 cm (11 inches) of either media or freeboard instead of using the customary 30.5 cm (12 inches) of graded gravel. Gravel-less support plates are made of high-density polyethylene beads that are sintered together. The pore space in the plate is similar to that of the barrier layer of gravel. Media, such as sand, anthracite, granular activated carbon, etc., can be placed directly on the surface of the plate. It has the added benefits that it eliminates the possibility of gravel disruption and simplifies media change-out such as for granular activated carbon reactivation.

The latest development for gravel-less media support is the use of direct slots for media retention, instead of the tortuous path employed by sintered beads. The first slots were 1 mm openings used to directly retain larger media such as 1.7 mm sand, primarily used in wastewater treatment in biological applications such as denitrification. In order to retain a smaller media such as 0.5 mm Effective Size sand, the direct slot was not easily manufactured. Therefore the use of an overlapping slot was employed to retain smaller media that would be used in drinking water filters. Currently an overlapping precision slot of 0.2 mm was developed to retain finer media.

FILTER INSTRUMENTATION

Updating the instrumentation and control system is essential in maintaining an efficiently run filter system. The control system can be designed to keep a constant watch on the essential parameters of the processes in the filter system. It will continuously monitor the condition of the filter to ensure optimum filtration. By continuously monitoring effluent water quality and filter conditions, the control system can automatically initiate the backwash sequence. This means that the filter is cleaned when it needs to be cleaned, as frequently or infrequently as changing conditions require and as long as necessary to clean the media. At the same time this eliminates the variations and accidents inherent in a manual backwash. Filter run times and water quality are optimized at the lowest possible costs. Keeping the filter media well-conditioned can lengthen the life of the filter system.

The filter control system can function as the plant Supervisory Control and Data Acquisition (SCADA) system. Using standard communications protocols that allow integration into the other Distributed Control Systems (DCS) and SCADA, the filter control system can be designed to control flow rate changes and automatically sequence equipment properly to avoid surges and potentially disastrous upsets which can damage equipment and effect water quality.

PROJECTED REHABILITATION COSTS

There are many examples of new construction and rehabilitation of existing gravity filters in different

Figure 13. Section View of the Filter Rehabilitation at Puengasi Water Treatment Plant in Quito, Ecuador
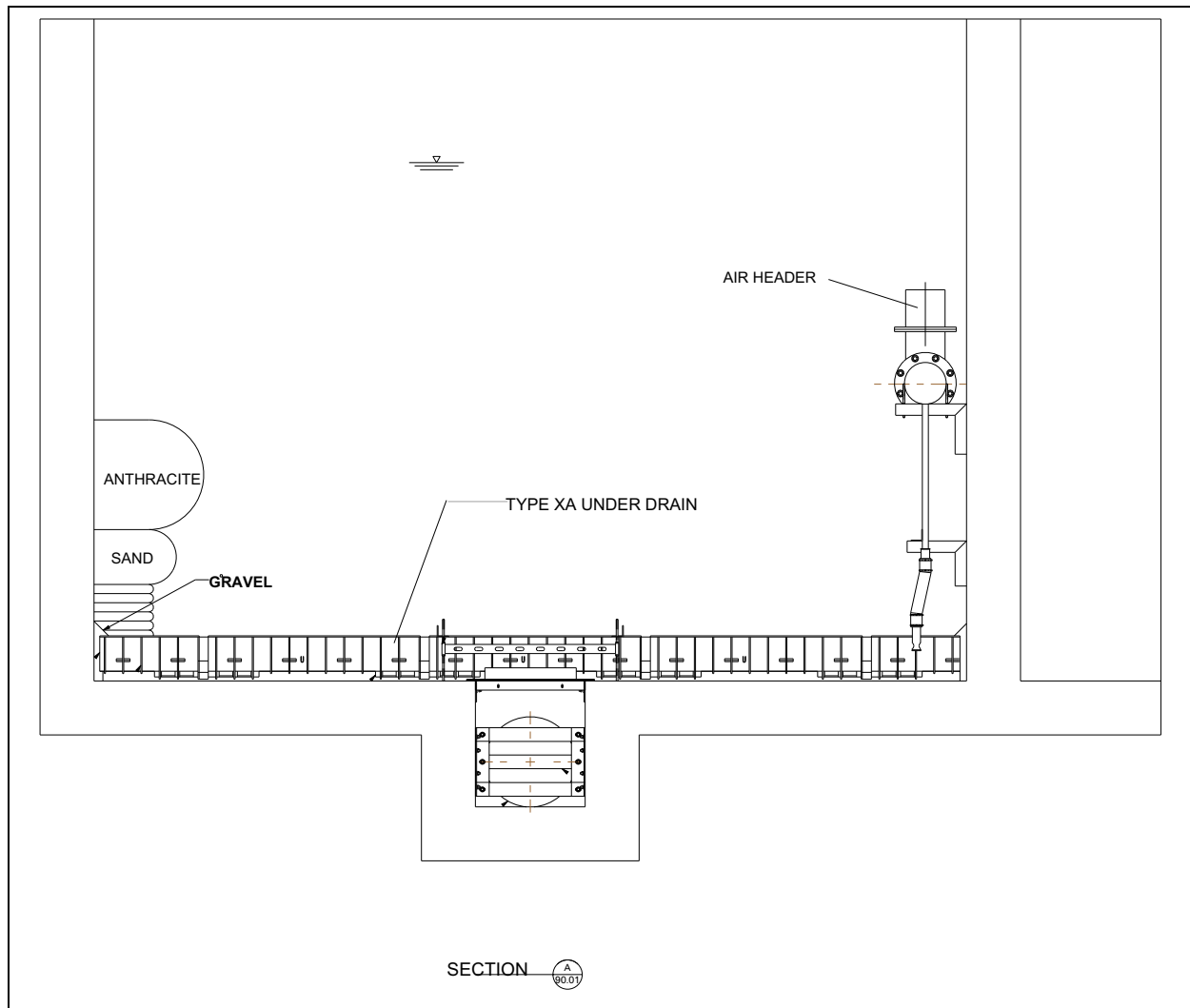
countries in Latin America. Examining these examples would be relevant for updating Cuba's water treatment systems. We chose below the example of the rehabilitation of the 8 filters at the Puengasi Water Treatment Plant in Quito, Ecuador. The 8 filters are 4.85 meters (15.9 feet) by 8.5 meters (27 feet) and were rehabilitated in January 2016. The original underdrain was a single pass nozzle type. Figure 13 shows the rehabilitation of one filter cell. A center flume was formed for the backwash water and filtered effluent water and the dual parallel lateral underdrain was placed perpendicular to the flume on top. Since there was not enough space in the center flume to accommodate a j-riser air header pipe, an overhead air header was supported on one wall to conduct the air to each individual lateral. The total cost for the equipment and installation for all filter cells was U$527,667. Since each filter design can be different, square meter pricing may not apply to other projects as the equipment can change substantially from project to project.

CONCLUSION

The dual parallel lateral has been successfully used in thousands of new and rehabilitated water and wastewater filter plant installations world-wide. The compensating secondary lateral has been shown to have superior backwash characteristics when compared to other types of single-pass underdrain systems. The

closely space orifices of the dual parallel lateral provide better distribution of backwash air and water which provides better cleaning of the filter media.

The dual parallel lateral is easily used to rehabilitate existing filter boxes. A low profile block coupled with the replacement of gravel with gravel-less support plates has enabled designers to install more media or

provide a greater freeboard depth. The greater flexibility of the dual parallel lateral has enabled designers to meet increasingly stringent regulatory requirements. As Cuba looks to upgrading its water treatment systems, dual parallel lateral might be the most efficient and cost-effective approach.

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