PALMER-BOWLUS FLUME

User's Manual

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INTRODUCTION TO THE PALMER-BOWLUS FLUME

Unlike most other flume styles that were developed to measure irrigation flows and then applied to other uses, the Palmer-Bowlus flume was specifically designed to measure sanitary sewage / wastewater flows.

The flume is a fixed hydraulic structure used to measure the flow of sub-critical waters in open channels with a constant cross-sectional area and a throat ramp.

Although originally developed to measure sanitary flows in-line with sewer conduits and pipes, Palmer-Bowlus flumes are now used in a range of applications, including:

- *Cooling water discharge*
- *Industrial effluent*
- *Mine discharge / dewatering*
- *Sanitary sewage (piped and treatment plant)*
- *Storm water*

FUNCTION

Sub-critical flumes like the Palmer-Bowlus flume operate by accelerating slow, sub-critical flow ($Fr<1$) to a supercritical state ($Fr>1$) by restricting the flow as it passes through the flume. The Palmer-Bowlus flume accomplishes this restriction by contracting the side walls and raising the floor of the flume (creating a throat ramp).

DESIGN

Designed for installation into existing manhole channels and in-line with sewer piping, Palmer-Bowlus flumes have a constant, U-shaped cross section to minimize the need to transition flow into / out of the flume.

The throat of the flume is created by a raised trapezoidal ramp section. As the floor of the ramp rises, the sidewalls also contract.

The result is that flow is accelerated through the throat by a combination of a change in floor elevation and vertical construction of the sidewalls.

Unlike the more common Parshall flume, there is no need to accommodate a change in elevation through the flume. Both the inlet and outlet of the Palmer-Bowlus flume are at the same elevation.

The design of the Palmer-Bowlus flume is dimensionless, with each flume sized based upon a standard design. The dimensions for any particular Palmer-Bowlus flume rely only on one dimension – D, the throat width of the flume. With D know, all the other dimensions of the flume can be readily determined.

STANDARDS

While an industry standard does exist for Palmer-Bowlus flumes, the standard is for the general class of flumes, not a specific design of them. Palmer-Bowlus flume designs are proprietary to each manufacturer – although most have settled on a trapezoidal throat ramp design.

- *ASTM D5390 – 93 (2013) Standard Test Method for Open Channel Flow Measurement of Water with Palmer-Bowlus Flumes*

ACCURACY

The accuracy of the Palmer-Bowlus flume is 3-5% under normal operating conditions – where the head in the flume is large in comparison to the length of the throat. For lower flows, where the head is low in comparison to the length of the throat, the accuracy decreased to +/-5-6%.

The decrease in accuracy reflects the increased importance of influence of the boundary layer at low flows.

Where the upstream / downstream / installation conditions are less than optimal or where the flume is out of dimension will exhibit accuracies less than above and may require field calibration.

Unlike the Parshall or Cutthroat flumes, the are no corrections for Palmer-Bowlus flumes that have settled (or been installed at a slope).

The above holds true for Palmer-Bowlus flumes experiencing free-flow. For installations where downstream conditions restrict the flow out of the flume, submergence may become a factor. There are no submergence corrections for Palmer Bowlus flumes and as such submerged flow conditions should be avoided.

DIMENSIONS

The master dimensions for (4) styles of Palmer-Bowlus flumes are given in Figures 1 through 4.

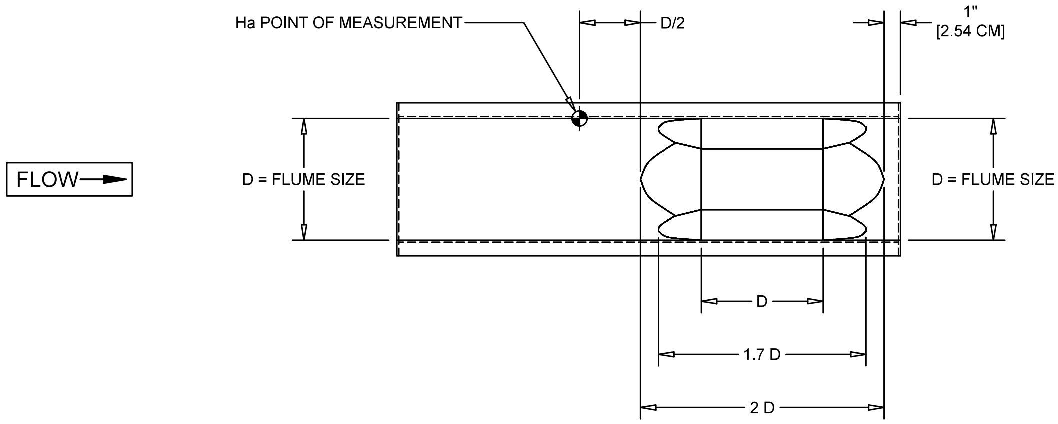
- *Permanent (4D+1") Style with Approach*
- *Permanent (2D+2") Style without Approach*
- *Insert (2D+2") Style*
- *Cutback (Insert) (2D+2") Style*

The flume length is given in ( ) (i.e. 4 x flume width + 1").

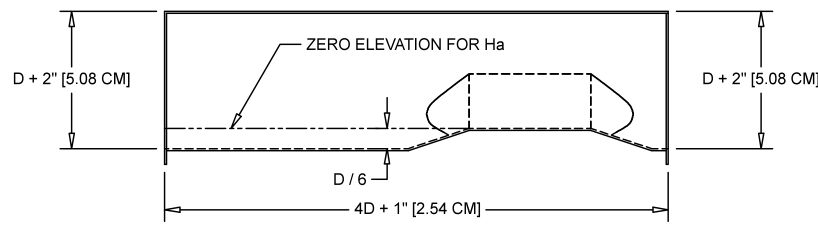
DIMENSIONAL TOLERANCES

In general, flumes dimensions should be within 2% of nominal for the standard free-flow equation to apply.

As long-throated flumes, the discharge characteristics of non-standard Palmer-Bowlus flumes can be by computer analysis.



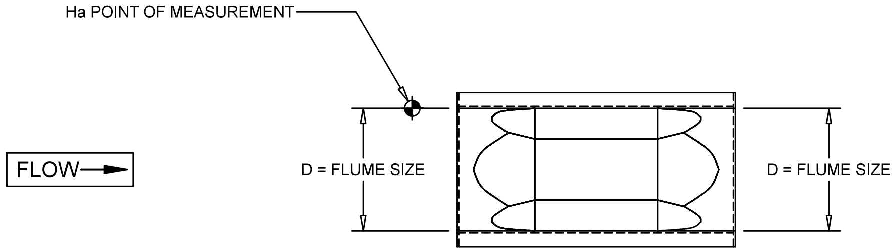
PLAN VIEW



ELEVATION VIEW

W (SIZE)	D/2	1.7 D	2 D	D + 2"	4D + 1"
4" [10.16 CM]	2" [5.08 CM]	6 51/64" [17.27 CM]	8" [20.32 CM]	6" [15.24 CM]	1'-5" [43.18 CM]
6" [15.24 CM]	3" [7.62 CM]	10 13/64" [25.91 CM]	12" [30.48 CM]	8" [20.32 CM]	2'-1" [63.5 CM]
8" [20.32 CM]	4" [10.16 CM]	1'-1 19/32" [34.54 CM]	1'-4" [40.62 CM]	10" [20.52 CM]	2'-9" [83.82 CM]
10" [25.4 CM]	5" [12.7 CM]	1'-5" [43.18 CM]	1'-8' [50.8 CM]	12" [30.48 CM]	3'-5" [104.1 CM]
12" [30.48 CM]	6" [15.24 CM]	1'-8 13/32" [51.82 CM]	2' [60.96 CM]	1'-2" [35.56 CM]	4'-1" [124.5 CM]
15" [38.1 CM]	7 1/2" [19.05 CM]	2'-1 1/2" [64.77 CM]	2'-6" [76.2 CM]	1'-5" [43.18 CM]	5'-1" [154.9 CM]
18" [45.72 CM]	9" [22.86 CM]	2'-6 19/32" [77.72 CM]	3' [91.44 CM]	1'-8" [50.8 CM]	6'-1" [185.4 CM]
21" [53.34 CM]	10 1/2" [26.67 CM]	2'-11 45/64" [90.68 CM]	3'-6" [106.68 CM]	1'-11" [58.42 CM]	7'-1" [215.9 CM]
24" [60.96 CM]	12" [30.48 CM]	3'-4 51/64" [103.63 CM]	4' [121.92 CM]	2'-2" [66.04 CM]	8'-1" [246.34CM]

Figure 1 – Permanent (4D+1”) Style Palmer-Bowlus Flume Master Dimensions



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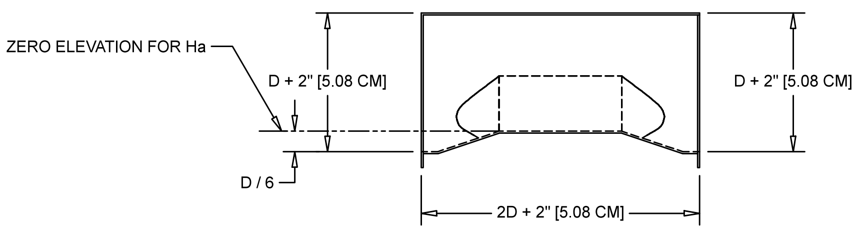
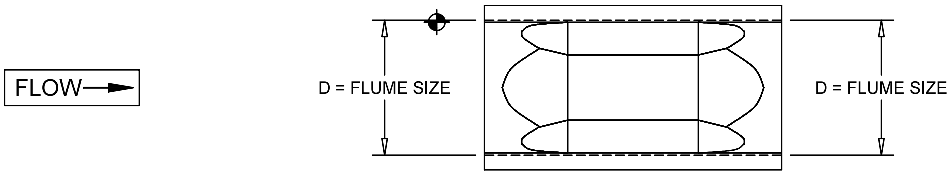


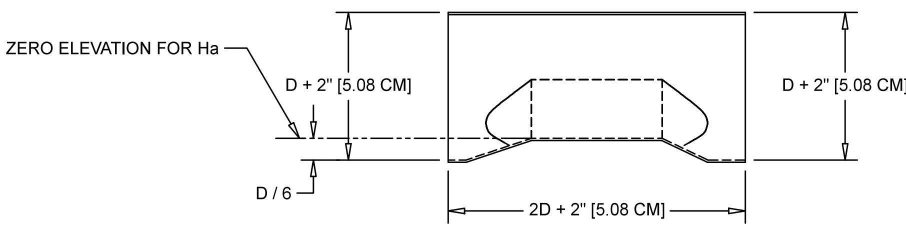
ELEVATION VIEW

W (SIZE)	D/2	1.7 D	2 D	D + 2"	2D + 2"
4" [10.16 CM]	2" [5.08 CM]	6 51/64" [17.27 CM]	8" [20.32 CM]	6" [15.24 CM]	10" [33.02 CM]
6" [15.24 CM]	3" [7.62 CM]	10 13/64" [25.91 CM]	12" [30.48 CM]	8" [20.32 CM]	1'-2" [35.56 CM]
8" [20.32 CM]	4" [10.16 CM]	1'-1 19/32" [34.54 CM]	1'-4" [40.62 CM]	10" [20.52 CM]	1'-6" [45.72 CM]
10" [25.4 CM]	5" [12.7 CM]	1'-5" [43.18 CM]	1'-8' [50.8 CM]	12" [30.48 CM]	1'-10" [55.88 CM]
12" [30.48 CM]	6" [15.24 CM]	1'-8 13/32" [51.82 CM]	2' [60.96 CM]	1'-2" [35.56 CM]	2'-2" [66.04 CM]
15" [38.1 CM]	7 1/2" [19.05 CM]	2'-1 1/2" [64.77 CM]	2'-6" [76.2 CM]	1'-5" [43.18 CM]	2'-8" [81.28 CM]
18" [45.72 CM]	9" [22.86 CM]	2'-6 19/32" [77.72 CM]	3' [91.44 CM]	1'-8" [50.8 CM]	3'-2" [96.52 CM]
21" [53.34 CM]	10 1/2" [26.67 CM]	2'-11 45/64" [90.68 CM]	3'-6" [106.68 CM]	1'-11" [58.42 CM]	3'-8" [111.8 CM]
24" [60.96 CM]	12" [30.48 CM]	3'-4 51/64" [103.63 CM]	4' [121.92 CM]	2'-2" [66.04 CM]	4'-2" [127 CM]

Figure 2 – Permanent (2D+2") Style Palmer-Bowlus Flume Master Dimensions



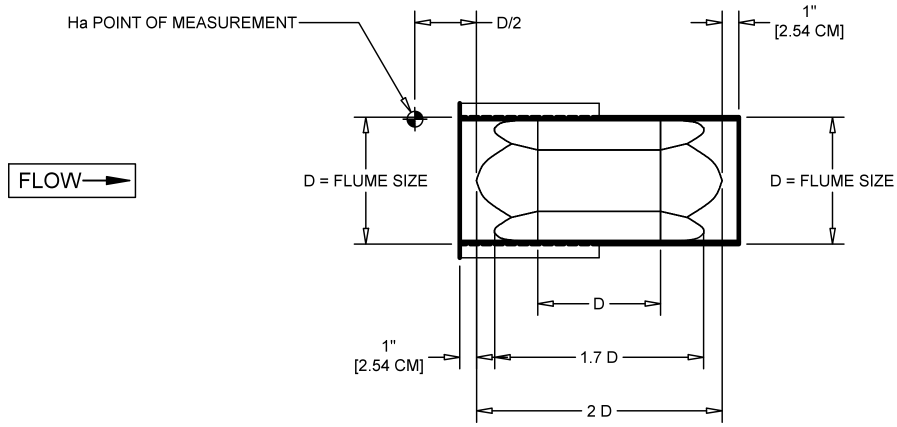
PLAN VIEW



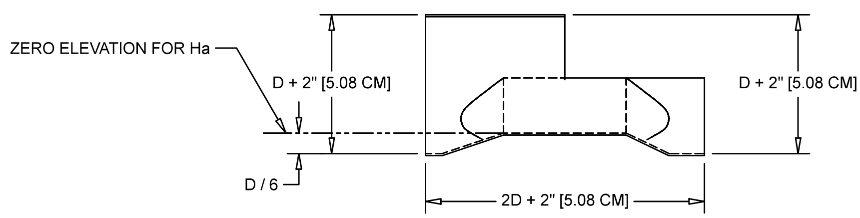
ELEVATION VIEW

W (SIZE)	D/2	1.7 D	2 D	D + 2"	2D + 2"
4" [10.16 CM]	2" [5.08 CM]	6 51/64" [17.27 CM]	8" [20.32 CM]	6" [15.24 CM]	10" [33.02 CM]
6" [15.24 CM]	3" [7.62 CM]	10 13/64" [25.91 CM]	12" [30.48 CM]	8" [20.32 CM]	1'-2" [35.56 CM]
8" [20.32 CM]	4" [10.16 CM]	1'-1 19/32" [34.54 CM]	1'-4" [40.62 CM]	10" [20.52 CM]	1'-6" [45.72 CM]
10" [25.4 CM]	5" [12.7 CM]	1'-5" [43.18 CM]	1'-8' [50.8 CM]	12" [30.48 CM]	1'-10" [55.88 CM]
12" [30.48 CM]	6" [15.24 CM]	1'-8 13/32" [51.82 CM]	2' [60.96 CM]	1'-2" [35.56 CM]	2'-2" [66.04 CM]
15" [38.1 CM]	7 1/2" [19.05 CM]	2'-1 1/2" [64.77 CM]	2'-6" [76.2 CM]	1'-5" [43.18 CM]	2'-8" [81.28 CM]

Figure 3 – Insert (2D+2") Style Palmer-Bowlus Flume Master Dimensions



PLAN VIEW



ELEVATION VIEW

W (SIZE)	D/2	1.7 D	2 D	D + 2"	2D + 2"
4" [10.16 CM]	2" [5.08 CM]	6 51/64" [17.27 CM]	8" [20.32 CM]	6" [15.24 CM]	10" [33.02 CM]
6" [15.24 CM]	3" [7.62 CM]	10 13/64" [25.91 CM]	12" [30.48 CM]	8" [20.32 CM]	1'-2" [35.56 CM]
8" [20.32 CM]	4" [10.16 CM]	1'-1 19/32" [34.54 CM]	1'-4" [40.62 CM]	10" [20.52 CM]	1'-6" [45.72 CM]
10" [25.4 CM]	5" [12.7 CM]	1'-5" [43.18 CM]	1'-8' [50.8 CM]	12" [30.48 CM]	1'-10" [55.88 CM]
12" [30.48 CM]	6" [15.24 CM]	1'-8 13/32" [51.82 CM]	2' [60.96 CM]	1'-2" [35.56 CM]	2'-2" [66.04 CM]
15" [38.1 CM]	7 1/2" [19.05 CM]	2'-1 1/2" [64.77 CM]	2'-6" [76.2 CM]	1'-5" [43.18 CM]	2'-8" [81.28 CM]
18" [45.72 CM]	9" [22.86 CM]	2'-6 19/32" [77.72 CM]	3' [91.44 CM]	1'-8" [50.8 CM]	3'-2" [96.52 CM]
21" [53.34 CM]	10 1/2" [26.67 CM]	2'-11 45/64" [90.68 CM]	3'-6" [106.68 CM]	1'-11" [58.42 CM]	3'-8" [111.8 CM]
24" [60.96 CM]	12" [30.48 CM]	3'-4 51/64" [103.63 CM]	4' [121.92 CM]	2'-2" [66.04 CM]	4'-2" [127 CM]

Figure 4 – Cutback (Insert) (2D+2") Style Palmer-Bowlus Flume Master Dimensions

POINTS OF MEASUREMENT

The primary, free-flow, point of measurement, Ha, is located D/2 (D = flume size) upstream of the beginning of the throat ramp. For short or insert style Palmer-Bowlus flumes, this point may be outside (upstream) of the flume itself.

The secondary point of measurement, Hb, used to determine the submergence of a Palmer-Bowlus flume is located in the channel downstream of the flume with the zero elevation the same as the height of the top of the throat ramp.

FLOW EQUATIONS

For free-flow conditions, the level-to-flow equation for the Palmer-Bowlus flume can be expressed as:

$$Q = KH_a{}^{n}$$

Q = free flow rate (cfs / m3/s)
K = flume discharge constant (varies by flume size / units)
H_a = depth at the point of measurement (feet / meters)
n = discharge exponent (depends upon flume size)

Equation 1 – Palmer-Bowlus Flume Free-Flow Equation

Size (D)	K (cfs)	K (m3/s)	N
4-inches	0.338	0.0479	1.9
6-inches	0.676	0.0959	1.9
8-inches	0.992	0.141	1.9
10-inches	2.06	0.264	1.9
12-inches	3.07	0.393	1.9
15-inches	4	0.624	1.9
18-inches	6	0.887	1.9
21-inches	8	1.135	1.9
24-inches	12	1.612	1.9

Table 1 – Palmer-Bowlus Flume Free-Flow Discharge Values

SUBMERGED FLOW

When downstream conditions reduce the flow out of the flume the flume is deemed to be submerged.

In order to determine if a Palmer-Bowlus flume is submerged, the submergence ratio must be calculated.

The submergence ratio is the ratio of the downstream depth at the secondary point of measurement, Hb, to the depth at the primary point of measurement, Ha.

$$S = \frac{H_b}{H_a}$$

Equation 2 – Submergence Ratio Equation

SUBMERGENCE TRANSITION

Typical of long-throated flumes, submergence transition (St) values for Palmer-Bowlus flumes range from 85 to 90%.

Unlike Parshall or Cutthroat flumes, there is no correction available when a Palmer-Bowlus flume becomes submerged and Openchannelflow recommends that Palmer-Bowlus flumes only be used in applications where they will not become submerged.

WHERE TO INSTALL A PALMER-BOWLUS FLUME

When selecting a site in which to install a Palmer-Bowlus flume there are several points to consider:

UPSTREAM OF THE FLUME

- *Flow entering the flume MUST be sub-critical.*
- *The Froude number (Fr) for flow entering a flume should not exceed 0.5 and should never exceed 0.99.*
    - *Surface turbulence may be encountered for Froude numbers above 0.5.*
    - *For a flume to accurately measure flow, that flow must be sub-critical (Fr<0.99).*
- *If the approaching flow is critical (Fr = 1.0) or supercritical (Fr > 1.0), then a hydraulic jump must be formed at least 30 times the maximum anticipated head upstream of the entrance to the flume.*
- *The flow entering the flume should be smooth, tranquil, and well distributed across the channel for 25 D (D = flume size).*
- *If the flow is super-critical approaching the flume a hydraulic jump must be formed well upstream of the flume or upstream energy absorbers and tranquilizing racks must be used).*
- *Should a hydraulic jump need to be formed to slow the flow, it should be forced to occur at least 30 Ha upstream of the flume.*
- *The approaching channel should be straight so that the velocity profile is uniform. Surging, turbulent, or unbalanced flows must be conditioned before the flow enters the flume.*
- *Any bends, dips, elbows, or flow junctions upstream of the flume must be sufficiently far upstream (25 D) so that the flow has is well distributed and non-turbulent.*

- *The site should allow the flow to smoothly transition into the flume.*
- *The upstream channel should be clear of vegetative growth.*
- *Open channel (non-full pipe) flow must be present under all flow conditions.*

FLUME LOCATION

- *The flume must be able to be set so that the throat ramp is level from front-to-back and from side-to-side.*
- *The throat ramp of the flume must be able to be set downstream.*
- *The flume must be centered in the flow stream.*
- *All of the flow must go through the flume – there should be no bypass.*

DOWNSTREAM OF THE FLUME

- *EPA guidelines call for the downstream channel to be straight for 5 to 20 throat widths – although flow spilling freely off the end of the flume can eliminate this requirement.*
- *Where an outlet adapter is used to transition the flow out of the flume, the connecting pipe must be of sufficient size, slope, and straight run so as to ensure that flow does not back up into the flume.*
- *The downstream channel must be clear of vegetative growth or the collection of debris so that flow does not back up into the flume.*

HOW TO INSTALL A PALMER-BOWLUS FLUME

Once a site has been selected, the flume must then be installed correctly:

- *The flume should be set so that it is centered in the flow stream.*
- *The upstream floor of the flume must be set high enough so that the flume does not operate under submerged flow conditions – as there is no correction for this.*
- *The outlet of the flume should be set at or above (ideally) the invert of the outlet channel / pipe to help transition solids out of the flume.*
- *The trapezoidal ramp of a Palmer-Bowlus flume must be level from front-to-back and from side-to-side (using a level on the top of the ramp – not the top of the flume).*
- *The flume must be braced internally (plywood and lumber are typically used) during installation to ensure that distortion does not occur.*
- *The flume must not float out of its intended final position during installation.*

BRACING THE FLUME

Most Palmer-Bowlus flumes ship with dimensional bracing (angle or tube) at the top of the flume. The bracing should be left on the flume until the installation has been completed.

If the flume is set in concrete, the bracing may be removed once the installation has been completed.

For installations where the flume is free-standing or otherwise not set in concrete, the bracing should be left in place.

If the bracing is removed, verify the dimensional accuracy of the flume after the removal.

CONNECTION JOINTS

Palmer-Bowlus flumes supplied with bulkheads, or transition sections must remain sealed between the joints.

While these joints may be sealed initially at the factory, a final visual inspection of all joints should be done before installation. Where required, apply one or two continuous beads of silicone on all seating surfaces before proceeding with the installation.

HOW TO MAINTAIN A PALMER-BOWLUS FLUME

For a Palmer-Bowlus flume to accurately measure flow, it must be periodically inspected and maintained. This inspection should be done six (6) months after installation and each following year.

The inspection should include the channel in which the flume is installed, the flow entering / exiting the flume, and the flume itself.

CHANNEL INSPECTION

- The upstream channel banks should be clear of vegetation or debris that could affect the flow profile entering the flume (upstream) or restrict flow out of the flume (downstream).
- Inspect the upstream channel to make sure that flow is not bypassing the flume.
- Inspect the downstream channel to make sure that scouring is not occurring.
- Any hydraulic jump should be at least 30 times the maximum head (Hmax) upstream of the flume.

FLOW INSPECTION

- *Flow entering the flume should be tranquil and well distributed.*
- *Turbulence, poor velocity profile, or surging should not be present.*
- *The Froude (Fr) number should, ideally, be 0.5.*
- *As the Froude number increases so does surface turbulence.*
- *Flumes accelerate sub-critical flow (Fr < 1) to a supercritical state (Fr 1>) .*
- *Flumes experiencing flows greater than unit (Fr = 1) will not accurately measure flow.*

FLUME INSPECTION

- *Flumes must be level from front-to-back and from side-to-side.*
- *Earthen installations are particularly susceptible to settling due to wet / dry and freeze / thaw cycles.*
- *Flow surfaces are to be kept clean of surface buildup or algal growth. Scrubbing or a mild detergent can be used.*