Updated Fact Sheet COA-1
For Certification of Trash Treatment Control Devices

Submitted To:

State Water Board
Municipal Stormwater Program Manager
1011 I Street
Sacramento, CA 95814

Submitted By:

Coanda, Inc.
3943 Irvine Blvd., #327
Irvine, CA 92602
(714) 389-2113

September10, 2021

COANDA
The Effect Matters

1. COVER LETTER

COANDA, Inc
3943 Irvine Boulevard # 327
Irvine, California 92602
(714) 389-2113
(714) 509-1640 Fax
www.coanda.com

September 10, 2021

Attn: Mary Boyd, Program Manager
State Water Board
Municipal Stormwater Program
1001 I Street
Sacramento, CA 95814

Via Email: Mary.Boyd@waterboards.ca.gov

Re: Updated Fact Sheet COA-1 for Certification of Trash Treatment Control Devices

Dear Ms. Boyd:

Coanda, Inc. is pleased to submit our Updated Fact Sheet COA-1 for certification of our Trash Treatment Control Devices in accordance with the State Water Board's application requirements.

Coanda, Inc. was chartered as a corporation under the laws of the State of California on May 22, 2008, and is headquartered in Irvine, Orange County, California. Cynthia L. Esmond is the President of Coanda, Inc. As Vice President, the undersigned is a duly authorized representative of the company. Coanda has been doing business in California since the date of inception. Our business address and contact information are identified in the header of this cover letter.

The devices covered in this application are proprietary configurations of Coanda Screens. The screens and our corporate name originate from the eponym "Coanda Effect," a technical term in published literature in the field of hydraulic engineering to define the behavior of a moving stream of fluid. Simply stated, the Coanda Effect says that "A moving stream of fluid in contact with a curved surface will tend to follow the curvature of the surface rather than continue traveling in a straight line."[1] Over 200 patents employing the Coanda Effect can trace their origins to this principle.

Coanda Screens are a proprietary technology. The undersigned is the co-inventor of US Patents Nos. 6,705,049; 7,258,785; 7,300,590; 7,584,577; 7,805,890; other patents pending. Coanda, Inc. holds an exclusive license under these patents to design, fabricate, and install proprietary Coanda Screens in California. Beyond California, our national partnership with Hydroscreen, Inc., LLC covers all of the United States and foreign countries.

Coanda products are fabricated at our shop in Denver, Colorado, located at 6803 E. 47th Ave., Denver, CO 80216.

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[1] Henri Coanda, "Device for Deflecting a Stream of Elastic Fluid Projected into an Elastic Fluid," US Patent No. 2,052,869, September 1, 1936.

A brief description of Coanda Screens is presented here, with further elaboration in Section 3, page 1. Coanda Screens are diagonally oriented, tilted wedgewire screens which can be installed in a variety of configurations, including inside of conventional curb entry storm water catch basins, vaults, and channels. Stormwater is introduced to the upper portion of the screen and flows flow down the smooth face where the sharp edges of the wedgewires divert water downward through the openings between each wire. Any trash or debris which may be present is too large to negotiate the openings, slides down the top face of the wedgewires into a trash collection compartment at the bottom.

The advantages of Coanda Screen BMPs are stated briefly as follows:

- They are designed to provide full capture trash removal at rated flow
- They remove all debris 1.0 mm and larger, the size of fine sand
- They remove other pollutants associated with the small particles of trash and debris between 1.0-5.0 m, as documented in numerous studies which are featured at: www.coanda.com
- They provide instantaneous debris and trash removal. All debris and trash typically dry quickly in the all-weather debris compartment where it can be readily removed with hand tools or moving equipment such as Vactor trucks
- Our BMPs are made of corrosion-free 100% stainless steel construction
- Our Channel Screens are fully engineered for each application
- Installation time is short and the effort is relatively easy
- There are no moving parts anywhere in the BMP
- Coanda Screens do not clog and have not failed in any of our installations
- The longevity of our Coanda Screens is measured in decades, perhaps 30-50 years
- When compared with other types of stormwater BMPs, Coanda Screens have superior performance and lowest overall life cycle cost including long term maintenance

Four configuration types are included in this Update. These are:

1. Coanda Channel Screen, described in Section 3.f.1.
2. Standard Coanda Curb Inlet BMP, described in Section 3.f.2.
3. Partial Width Isolated Coanda Curb Inlet BMP, described in Section 3.f.3.
4. Partial Width Open Coanda Curb inlet BMP, described in Section 3.f.4.

Since the inception of Coanda, Inc. in 2008, our market has grown significantly in California, nationally and internationally. Refer to our website for information regarding our installations, www.coanda.com.

The following is a shortlist of three locations with contact information for municipalities in California where the device has been installed:

Coanda Curb Inlet BMP: City of San Diego Jim Harry, Senior Planner, Stormwater Department, (619) 247-5661, jharry@sandiego.gov; or the City's consultant, Kim Truong, Tetra Tech, (858) 609-1629, kim.truong@tetratech.com.

Coanda Curb Inlet BMP: City of Fontana, Abigail Gomez, Environmental Control Supervisor, Public Works Department, (909) 350-6772, agomez@fontana.org

Coanda Channel Screen: County of Orange, Chris Crompton, Ph.D., Orange County Watershed Manager, (714) 955-0630, chris.crompton@ocpw.ocgov.com; or the County's consultant, Joseph Long, PE, (714) 352-1528. joseph.long@stantec.com.

Los Angeles County Department of Public Works performed extensive testing on our Coanda Curb Inlet BMP in 2011 at its full scale test facility at San Gabriel Dam. Several technical reports came from this testing which demonstrated the efficacy of Coanda Screens. Subsequently, LA County sponsored the application of Coanda, Inc. to receive full capture certification by the LA Regional Board, which was granted on November 15, 2011.[2] A copy of the certification letter is contained in Appendix B. Other agencies, public and private, including Federal and local agencies and major universities have also tested Coanda Screens. Refer to the summary presented in Section 8 and in the Appendices.

In this Update we describe the advantages, limitations, operational, sizing and maintenance considerations of Coanda Screens. Briefly, Coanda Screens remove particles 1.0 mm and greater. Coanda screen openings cannot be enlarged to 5.0 mm without defeating the non-clogging aspect of this technology. Therefore, our products over-achieve the State's 5.0 mm particle size. This is not a deficiency, because studies have demonstrated significant water quality benefits associated with removing particles smaller than 5.0 mm. At the same time, Coanda Screens have a very high flux rate and are able to handle much larger volumes of flow without plugging than any conventional screen of which we are aware. We understand most laymen have probably never seen or understood a non-clogging screen. Yet, to the best of our knowledge, not one of our Coanda Screens has ever plugged with trash or caused a hydraulic backup or ponded water inside the BMP.

The retained trash in our Coanda BMPs typically dries quickly and to date has not been identified as a breeding ground for bacteria or vectors or for the genesis of odor problems. To date, none of our clients has reported a mosquito manifestation emanating from a Coanda BMP.

Coanda, Inc. strives to be a good corporate citizen, by donating to scholarships and sponsoring public education events and supporting environmental awareness activities.

[2]http://www.waterboards.ca.gov/losangeles/water_issues/programs/tmdl/fcc/Coanda%20Screens%20Certification%2011152011.pdf.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons that manage the system or those persons directly responsible for gathering the information, to the best of my knowledge and belief, the information submitted is, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Please contact us at the above address, or by phone or email shown below if you wish to clarify anything in our application.

Very truly yours,
COANDA, INC.

Steven E. Esmond, P.E.
Vice President
sesmond@coanda.com

c: Leo Cosentini, State Water Board, Leo.Cosentini@waterboards.ca.gov
MVAC, trashtreatment@mvcac.org

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3. PHYSICAL DESCRIPTION

Coanda Screens are diagonally oriented, tilted wedgewire screens which can be installed in a variety of configurations, including inside of conventional curb entry storm water catch basins. Figure 3.1 is a close-up illustrating how the screens are mounted at an angle. Stormwater is introduced to the upper portion of the screen. As water and trash flow down the face, the sharp edges of the wedgewires divert water downward through the openings between each wire. Any trash or debris which may be present, being too large to negotiate the openings, slides down the top face of the wedgewires into a trash collection compartment at the bottom. To provide a quick introduction to anyone not familiar with this technology, we invite the reader to watch a short video at: https://youtu.be/hrI5A7x1kEI, or at: https://coanda.com/, scroll down and click on the video.

Figure 3.1 Side View Close-up of Coanda Screen

Coanda Effect screens have been used for decades to screen small aquatic organisms and debris from water diversions. For more technical information on the theory and practical application of Coanda screens, refer to the U.S. Bureau of Reclamation web site.[3] Applications of Coanda Screens designed specifically to remove debris from urban storm water have become increasingly popular across the United States, due in part to the screens' advantages.

> *"These screens have large flow capacities and are hydraulically self-cleaning without moving parts, so they require minimal maintenance."*[4]

3a. Trash Capture

Coanda Screens and all appurtenances are made entirely of 304 stainless steel, a material which provides superior corrosion resistance and high strength. The tilted wedgewire Coanda screen is designed to divert all stormwater runoff in a downward, vertical direction upon making contact with the Coanda Screen. The Coanda Screen is typically mounted immediately inside a conventional catch basin at a diagonal orientation of 35 to 45 degrees from horizontal. The Coanda Screen shown in Figure 3.2 is configured for a curb inlet vault. Clear spacing between adjacent wedgewires is uniformly set at 1.0 mm. Some stormwater installations may utilize a spacing of 0.5 mm. No debris larger than the wedgewire spacing can physically pass through the clear spacing and is therefore excluded from the stormwater flow. As all storm runoff is diverted through the Coanda Screen, trash and debris are left behind and will slide down the face of the screen into a debris compartment in the lower left quadrant of the catch basin. Hence, all trash is

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[3] United States Bureau of Reclamation, http://www.usbr.gov/pmts/hydraulics_lab/twahl/coanda/.

[4] Wahl, Tony L., "Design Guidance for Coanda-Effect Screens," US Department of the Interior, Bureau of Reclamation, Technical Service Center, Water Resources Research Laboratory, Denver, Colorado, Report No. R-03-03, July 2003, http://www.usbr.gov/pmts/hydraulics_lab/pubs/R/R-2003-03.pdf

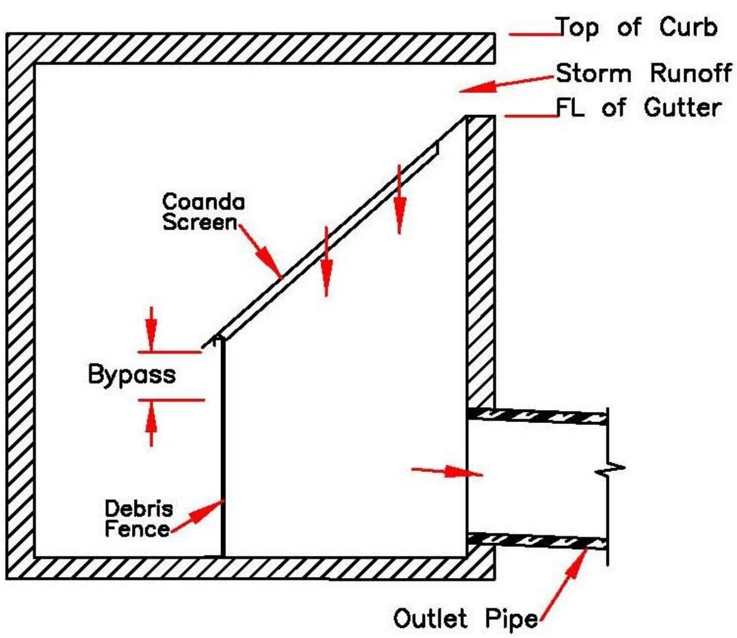

Figure 3.2 – Typical Coanda Curb Inlet Cross Section

instantaneously and permanently separated from stormwater runoff at the face of the Coanda Screen. This is illustrated on Figure 3.2. Unlike conventional screening devices, Coanda Screens do not plug because the trash that is separated from stormwater slides down the face of the screen and is not trapped in the openings between adjacent wires. The operating principle is that Coanda Screens separate water from trash, whereas all other screens attempt to separate trash from water, thereby competing for the same screen openings. Since Coanda Screens are self-cleaning, there is no competition for the same openings, consequently there have been no blockage problems in any of our installations.

Only minor drippage water associated with trash and debris would ever be able to make its way to the debris compartment. All separated debris is trapped in the debris storage compartment and typically air-dries very quickly after a storm event. Eventually, the collected debris and trash are removed from the catch basin by maintenance crews.

The element separating the debris compartment from the plenum underneath the Coanda Screen is referred to as a Debris Fence, which in curb inlets is usually made from stainless steel perforated plate, a material with numerous holes arranged in a tight pattern. The net open area of the Debris Fence perforated plate material is approximately 50 percent. Each hole is typically 2 mm to 4 mm in diameter. Thus, there is no opening anywhere in the Coanda catch basin larger than trash, which by definition is 5 mm. The only exception is the overflow section, which is further explained below under each configuration in Sections 3.f.1 through 3.f.4.

Most regulatory jurisdictions require the BMP to have some sort of emergency bypass in anticipation of peak flows or in the event of a blockage of the primary screening element. Angeles County Flood Control District (LACFCD) requires that the minimum size of an individual bypass opening be no smaller than 6 inches by 6 inches. Therefore, in each Coanda catch basin BMP a bypass section is provided along the top of the debris fence. The bypass section consists of a series of 6 x 6 inch square openings arranged in sequence at the top of the debris fence, lined up in a row, each opening spaced about 6 inches apart. The necessary number of openings of this size is dictated by the hydraulic requirements of the bypass flow rate.

3.b Peak Flows / Trash Volumes
Each BMP can be designed to achieve a designated peak flow rate and trash capture volume. The design flow is not limited to the 1-year, 1-hour storm. Typically, the peak flow design of a Coanda Curb Inlet BMP will exceed the peak flow of the vault. In other words, trash can be removed from all flows that enter and exit the vault.

The design of the debris storage compartment in any Coanda BMP can be adjusted to provide the exact amount of required debris storage based upon local conditions. In general, our experience indicates that typical trash loading rates are in the range of about 10-15 cubic feet per acre per year, except where specific conditions dictate otherwise. The volumes of trash captured in our BMPs have bulk densities which are typical for urban trash in most municipalities, we find generally in the range of about 15-25 lbs per cu.ft., and may vary depending upon land use.

3.c Hydraulic Capacity
The basis of hydraulic design capacity for any catch basin BMP is ultimately derived from the hydraulic capacity of the catch basin itself. The applicable hydraulic capacity can be determined from Chart D-10D of the LACFCD Hydraulic Manual.[5] The LACFCD states, *Curb opening catch basins are not installed on slopes larger than 0.04, so a slope of 0.04 can be assumed to be the maximum slope.*[6] Steeper slopes on city streets produce higher flow rates for any given storm. However, LACFCD has determined that the maximum flow for any catch basin will not exceed that which is based on a street slope of 0.04 percent. Using the data on LACFCD Chart D-10D, and applying a street slope of 0.04, the following equation was derived to describe the relationship between maximum flow Q and catch basin width:

Equation 1: $Q = 70\,(1\text{-exp}^{-0.02xCB})$, cfs

where CB = catch basin width, ft.

There may be instances in which the designer could use a flatter street slope when it is known, or an approved flow rate other than the maximum capacity of the catch basin. Frequently, public infrastructure storm conveyance capacity may be designed to handle a ten-year storm event, defined as Q_{10}. The one-year one-hour storm event is designated by $Q_{1\text{-}1}$. The following equations are extracted from the LACFCD methodology to be used to compute Q_{10} and $Q_{1\text{-}1}$:

Equation 2: $Q_{10} = 0.75\ Q$

Equation 3: $Q_{1\text{-}1} = 0.22\ Q_{10}$

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[5] "Hydrology Manual," Los Angeles county Department of Public Works, January 2006, http://www.ladpw.org/wrd/publication/.
[6] LACFCD Submittal to LARWQCB, April 2007, p. 6.

Once the proper design flow rates have been established, whether Q, Q_{10}, or Q_{1-1}, the designer is ready to proceed with the design of the Coanda catch basin BMP.

3.c.1 Catch Basin Design

Figure 3.3 depicts the catch basin in elevation, featuring the critical dimensional components. The first step is to calculate the Coanda screen length, L_c, which is determined from the hydraulic design one-year, one-hour flow rate Q_{1-1}. For urban storm water applications involving screen openings of 0.5 mm or 1.0 mm, with the Coanda screen mounted at an angle that generally ranges from 35 to 45 degrees, a very conservative hydraulic loading established by LACFCD is 250 gpm per sq.ft. Substantially higher loadings can be derived using USBR design criteria, but this design loading set intentionally low enough to allow for the interference of debris, long term wear and tear over a 30-50 year life cycle, and imperfections in the street and gutter controlling entrance flows outside of the vault.

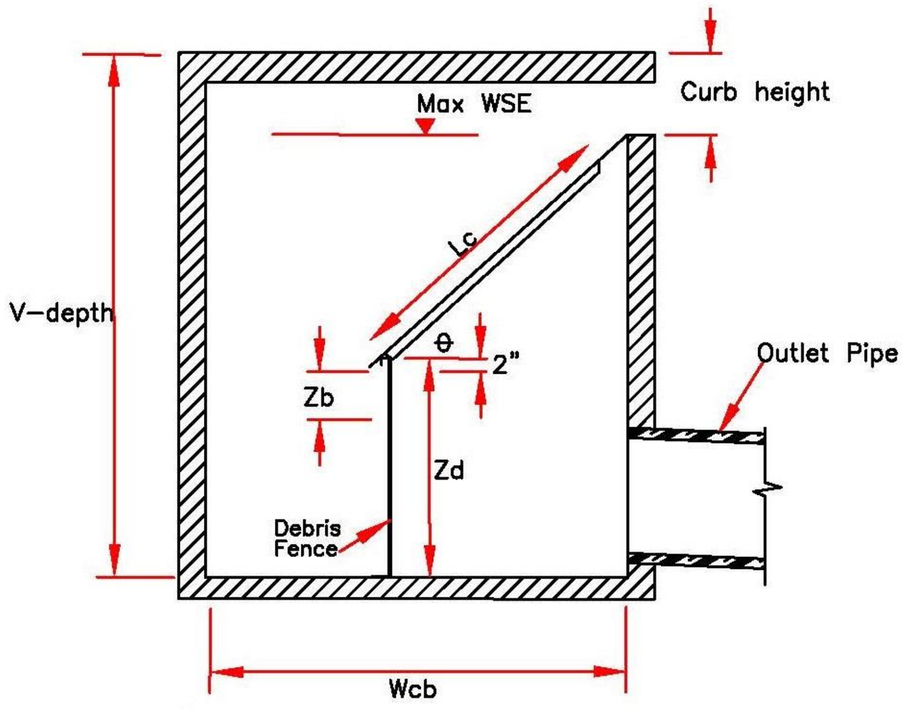


Figure 3.3 – Coanda BMP Dimensional Variables

Calculate L_c

The length of the Coanda screen L_c can be calculated as follows. Assume the debris fence is positioned along the centerline of the vault as depicted in Figure 3.3. The angle of the Coanda Screen (θ) is typically in the range of 35-45 degrees.

Equation 4: Lc = (Wcb, feet) / 2 cos θ, feet

The designer will establish the angle of the screen (θ). The range as stated above should be between 35 to 45 degrees with respect to horizontal. Contributing to this decision will in part be the depth (V-depth) and width of the catch basin (Wcb).

Each Coanda Screen comes with a stainless steel approach plate welded along the top which is securely anchored to the catch basin using stainless steel anchor bolts. A stainless steel toe plate welded along the bottom which is securely anchored to the debris fence in the field using stainless steel bolts. No welding should be performed in the field. The top of the Coanda Screen's approach plate is located just inside the catch basin, at or below the flow line of the gutter, therefore does not interfere with anything at or on the street. The Coanda Screen will not interfere with street sweepers, since it is installed in the gutter just inside the catch basin opening. Because these installations have no mechanical devices above the gutter elevation, there need not be any allowance for freeboard. Thus, the maximum depth of flow can be taken as the distance from the flowline of the gutter to the floor of the catch basin. In Figure 3.3, this distance is the V-depth minus the curb height. Curb height is generally around 7 to 9 inches.

Calculate Z_d

Next, determine the height of the debris fence Z_d shown in Figure 3.3. If the floor of the vault is flat, then:

$$Z_d = \text{V-depth} - \text{Curb Height} - (0.5 \times \text{Wcb} \times \tan\theta)$$

One may wish to maximize the height of the debris fence Z_d in order to maximize the volume of debris compartment. It is most often the case that the designer will locate the debris fence along the midpoint or centerline of the catch basin. Thus, the value of Z_d is ultimately derived from the angle and length of the Coanda Screen as well as of the geometry of the catch basin itself.

The hydraulic properties of the Coanda BMP are illustrated in Figure 3.4.

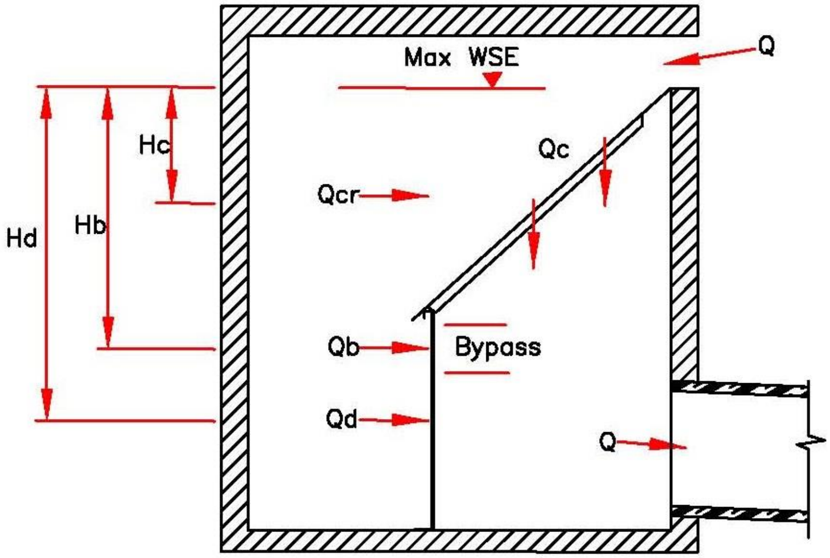


Figure 3.4 – Coanda BMP Hydraulics

Determine the hydraulic capacity of the debris fence using the orifice equation:

Equation 5: $Q = C\,A\sqrt{2gH}$, cfs

For all calculations involving Equation 5, the value of $g = 32.2$ ft sec^{-2}. In keeping with LACFCD standard practice, the orifice coefficient C for the bypass is 0.60, and for the debris fence is 0.53.[7] The cross sectional area A is the area of the debris fence in square feet (less the area of the bypass A_b), multiplied by the ratio of the net clear opening, which for typical perforated plate debris fence material is 0.50. The value of the head H is equal to H_d (shown in Figure 3.4), being the distance in feet from the maximum water surface to the vertical centroid of the debris fence.

Using this information, the value of Q_d (flow rate through the debris fence) can be calculated. The calculated value of Q_d should be equal to or greater than the maximum flow Q. Should the calculation reveal a hydraulic deficiency, the designer should re-visit the geometry of the catch basin or change the Coanda Screen angle in order to adjust the size of the debris fence accordingly.

[7] Ibid, p. 9.

Calculate Z_b
Next, determine the hydraulic capacity of the bypass section. Refer to Figure 3.3. Having determined the height of the debris fence Z_d, the top of the bypass openings will normally be set 2 inches below the top of the debris fence. The minimum bypass opening Z_b (set by LA County) is 6 x 6 inches. Typically, Z_b will be set at 6 inches unless larger openings are needed to handle the bypass flow.

Again employ Equation 5, using a C-coefficient of 0.60 and H set at the value of H_b (shown in Figure 3.4), which is the distance from the maximum water surface to the centroid of the bypass openings. The total bypass opening area is determined by multiplying the total length of the bypass openings L_b times their vertical height Z_b. In most Coanda BMP installations, the bypass section will be a series of 6-inch by 6-inch slots located 2 inches below the top of the debris fence, each slot separated from the next slot by 6 inches of debris fence. Thus, the value of L_b can be approximated for any length of catch basin using the following equation:

Equation 6: $L_b = (CB – 1) \times 6$ (inches)

where CB = length of catch basin in feet.

The area of the bypass can be calculated as follows:

Equation 7: $A_b = L_b \times Z_b$

Using Equation 5, substituting A_b for A and H_b for H, the designer will calculate the bypass flow rate Q_b. If this calculation reveals the bypass has insufficient hydraulic capacity, then the designer will increase the values of L_b and/or Z_b accordingly, taking into account the practical implications on the geometry of the debris fence and its necessary function.

Optional Calculation of Reverse Coanda Screen Flow Q_{cr}
As a final but optional check, the designer can evaluate what might happen if both the debris fence and the bypass were to become plugged, and if the water were to enter the catch basin without passing through the Coanda screen. This condition would be analogous to Q_{cr} (shown in Figure 3.4), where the flow would go in a reverse direction through the Coanda Screen openings. In this situation, the Coanda Screen would behave as an orifice. The designer could use Equation 5, taking A as the area of the Coanda screen times 0.30 (typically the net clear opening for most Coanda screens), H set at a value of H_c (Figure 4), corresponding to the distance from the maximum water elevation to the centroid of the Coanda screen, and a C-coefficient of 0.53. Such a condition is almost never seen in practice, but was intentionally created at the County of Los Angeles Department of Public Works test facility at the San Gabriel Dam on March 2, 2011. Both the debris fence and the bypass were intentionally covered and taped with plastic, forcing all flow to go through the Coanda screen either in the normal or reverse direction. Flow was increased to the maximum that could be delivered to the catch basin. The peak design flow of the vault itself without any BMP, was ably handled by the Coanda Screen, as can be seen in the

video below.[8] As well, a short companion video shot underneath the Coanda Screen confirms the peak flow is being processed by the Coanda Screen and not the debris fence or the emergency bypass.[9]

Example Calculation
Assume that a standard Los Angeles County catch basin that is 10 feet wide and has a V-depth of 4.5 feet, is to be retrofitted with a Coanda BMP.

Flows
Using Equation 1: $Q = 70\ (1\text{-}exp^{-0.02xCB})$, cfs

where CB = catch basin width = 10 ft, Q = 12.7 cfs.

Using Equation 2: $Q_{10} = 0.75\ Q = 9.5$ cfs

Using Equation 3: $Q_{1\text{-}1} = 0.22\ Q_{10} = 2.1$ cfs

Coanda Screen
Using Equation 4: Lc = Wcb / 2 cos θ, feet

where vault width Wcb is 3.0 feet and screen angle θ is 40 degrees. Using Equation 4 above, L_c = 1.96 feet.

Debris Fence
The next step is to determine the height of the debris fence. Using Equation 4:

Z_d = V-depth – Curb Height – (0.5 x Wcb x tan θ)

In this case, Z_d = 4.5 – 8/12 – 0.5 x 3.0 x tan (40) = 2.57 ft.

Next, calculate the bypass open area A_b. Use Equation 6 to calculate the required length of bypass openings L_b = (CB – 1) x 6 = 54 inches = 4.5 feet. Thus, according to Equation 7, using bypass height of 6 inches, the total bypass area $A_b = L_b$ x Z_b = 4.5 x 0.50 = 2.25 sq.ft.
The net open area of the debris fence = (Z_d x CB – A_b) x 0.50 = (2.0 x 10 -2.25) x 0.50 = 8.87 sq.ft. The average hydraulic head on the debris fence is estimated to be 23 inches or 1.91 feet. Using Equation 5, with C = 0.53, A = 8.87, and H = 1.91, the resulting Q_d = 52.1 cfs. (The debris fence must have a hydraulic capacity of at least Q or 12.7 cfs, therefore, the debris fence is adequate to carry the maximum flow.)

[8] Video showing Coanda BMP undergoing testing at LACFCD San Gabriel Dam Test Facility, March 2, 2011, http://www.youtube.com/watch?v=8EB8OAI3T-g
[9] Video confirming Coanda Screen (not the debris fence) is handling the flow: https://youtu.be/_0G5Vyftxxg

Bypass
Having previously calculated the bypass area A_b to be 2.25 sq.ft., the hydraulic head acting upon the bypass open area is estimated to be 15 inches or 1.25 feet. Using Equation 5, with C = 0.60, A = 2.25, and H = 1.25, the resulting Q_b = 12.1 cfs. The bypass section must have a hydraulic capacity of at least Q or 12.7 cfs, therefore, the bypass openings need to be increased from a 6 inch width to 7 inches. Using Equation 6, the revised bypass opening would be: L_b = (CB – 1) x 7 = 63 inches = 5.25 feet. Changing the bypass width from 6 to 7 inches therefore increases the value of A_b from 2.25 sq.ft. to 2.63 sq.ft. Re-calculating the bypass hydraulic capacity using Equation 5, with C = 0.60, A = 2.63, and H = 1.25, the resulting Q_b = 14.1 cfs. The bypass section must have a hydraulic capacity of at least Q or 12.7 cfs, therefore, 7 inch wide x 6 inch high bypass openings will be more than adequate to carry the maximum flow.

Reverse Flow Through Coanda Screen
The net open area for the Coanda screen (A_{cr}) is its length times its width times the net clear opening, which is 0.30. Thus, $A_{cr} = L_c$ x CB x 0.30 = 0.38 x 10 x 0.30 = 1.14 sq.ft. The hydraulic head acting upon the Coanda screen is estimated to be 6 inches or 0.50 feet. Using Equation 5, with C = 0.53, A = 1.14, and H = 0.50, the resulting Q_{cr} = 3.4 cfs. The Coanda screen in this example is designed to carry the Q_{1-1} flow of 2.1 cfs. Note that the BMP design does not depend on Q_{cr} at all, because the debris fence and the emergency overflow are each designed to carry the maximum flow Q.

Screen Blinding
The hydraulic capacity of the Coanda Screen devices at 50 percent screen blinding has not been provided because the device screen does not become blinded.

3.d Comparison Table
The peak Q in the following table is based upon the LA County design standards using Equation 1. The ten-year flow Q_{10} and the one year one hour storm flow Q_{1-1} are calculated according to Equation 2 and 3, respectively. For the example presented above, the following table also presents the rated capacity of the Coanda Screen (Qc) as a function of the curb inlet width. The rated capacity of the debris fence (Qd) is shown below, as well as the rated capacity of the internal bypass (Qb). Trash volume, shown in the second column, is based upon trash levels allowed to accumulate in the vault up to the bottom of the emergency overflow slots which provides internal bypass. Generally speaking, the Coanda Screen in this example would be treating at least 80 percent of the peak flow, which far exceeds the State standard of the 1-year, 1-hour storm event Q_{1-1}. Furthermore, there is room in this example for the Coanda Screen to be enlarged slightly if desired to match the capacity of the peak Q of the vault.

Width of Curb Inlet (Ft)	Trash Capture Vol, cu.ft.	Peak Flow Q, cfs	Q_{1-1}, cfs	Qc, cfs	Qd, cfs	Qb, cfs
3	8.57	4.08	0.67	3.27	26.13	2.40
4	11.42	5.38	0.89	4.37	34.84	3.19
5	14.28	6.66	1.10	5.46	43.55	3.99

Width of Curb Inlet (Ft)	Trash Capture Vol, cu.ft.	Peak Flow Q, cfs	Q_{1-1}, cfs	Qc, cfs	Qd, cfs	Qb, cfs
6	17.13	7.92	1.31	6.55	52.26	4.79
7	19.99	9.14	1.51	7.64	60.97	5.59
8	22.84	10.35	1.71	8.73	69.68	6.39
9	25.70	11.53	1.90	9.82	78.39	7.19
10	28.55	12.69	2.09	10.91	87.10	7.98
11	31.41	13.82	2.28	12.00	95.81	8.78
12	34.26	14.94	2.46	13.10	104.52	9.58

3.e Design Drawings
There are no standard sizes *per se* which pertain to the Coanda Screen configurations in this Update. Refer to design drawings and photographs of the four configurations as presented in the following sub-sections 3.f.1 through 3.f.4.

3.f Configurations
A total of four configurations are presented in this section, which also provide drawings and photographs as applicable. Each configuration is explained as follows.

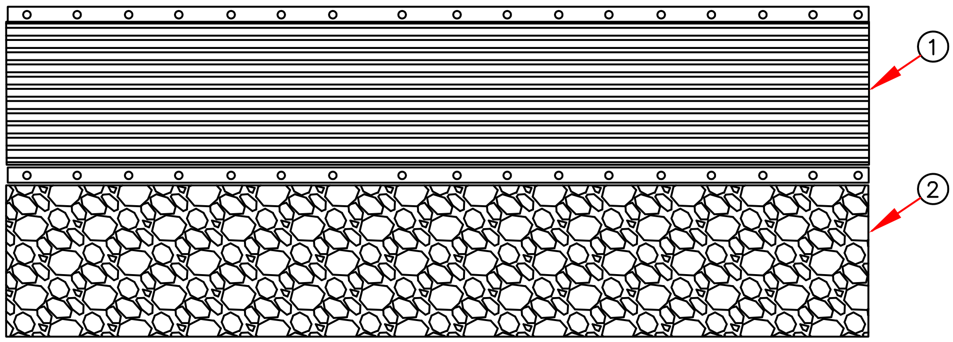
3.f.1 Coanda Channel Screen BMP
Depicted in Figure 3.5 is the standard configuration of a Coanda Channel Screen BMP. These are end-of-pipe trash removal devices which are used worldwide and throughout California. These are stand-alone, full engineered BMPs, positioned at strategic points in the MS4 system to treat the Q_{1-1} or higher flows, as well as all non-storm low flow first flush. The 1.0 mm Coanda Screen is the primary means and also the sole means of trash removal. No trash can fit through 1.0 mm openings and there are no other openings. All trash winds up in the debris compartment, where it quickly air-dries and remains until removed by maintenance crews. The debris fence for Coanda Channel Screens is replaced by a solid wall, usually reinforced concrete. Refer to photos of this design in Figure 3.6.

a. Hydraulic Capacity

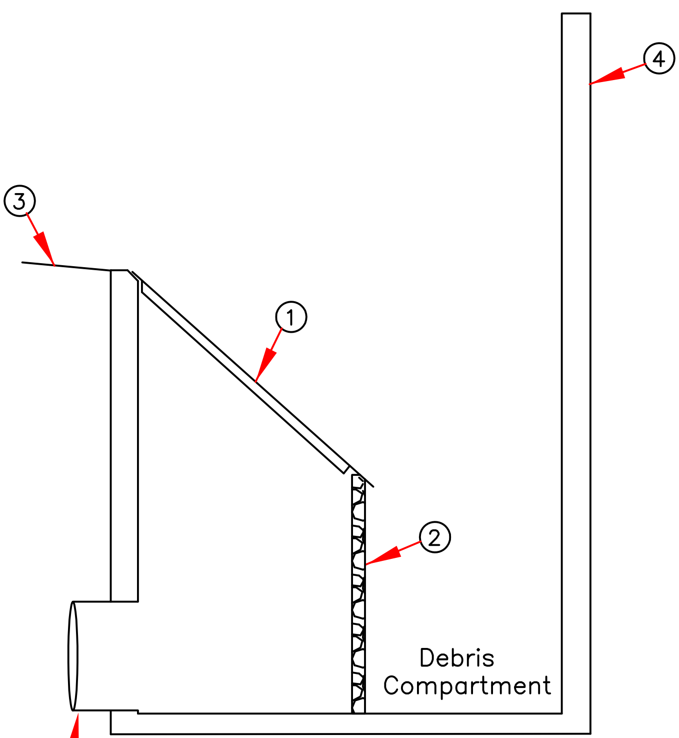
The hydraulic capacity of Coanda Channel Screens is not determined as previously described in this section, but by computer models, including a proprietary model developed by Coanda, Inc. and the public domain computer model developed by the US Bureau of Reclamation. These and some other models have been validated by physical test data based upon actual field measurements, and take into account all the controlling variables including screen size, tilt, angle, wire size, wire spacing, and approach conditions. These models generally yield design capacities for Coanda Channel Screens that may vary from 0.5 to 1.3 cfs per sq.ft.

b. Vector Control

A vector control waiver for an access hatch is being requested for the Coanda Channel Screen configuration. In all of the hundreds of Coanda Channel Screens which have been built to date, we know of none which have an access hatch into the plenum underneath the Coanda Screen.



Elevation View Facing Channel Screen



Channel Screen End View

Outlet Pipe

Notes
1. Coanda Screen
2. Solid Interior Structural Wall
3. Flowline of Existing Channel
4. Structural Wall of Existing Channel

Note: the entire BMP is in an open air environment, not inside a vault.

US Patent Nos. 6,705,049, 7,258,785, 7,300,590, 7,584,577, 7,805,890; other patents pending.

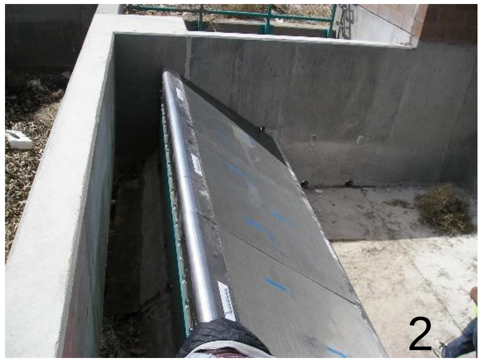
COANDA The Effect Matters	Figure 3.5 Channel Screen BMP	SEE 031621	NO SCALE

Figure 3.6

COANDA CHANNEL SCREEN

THE SOLUTION FOR REMOVING TRASH & DEBRIS FROM LARGE FLOWS


1


2

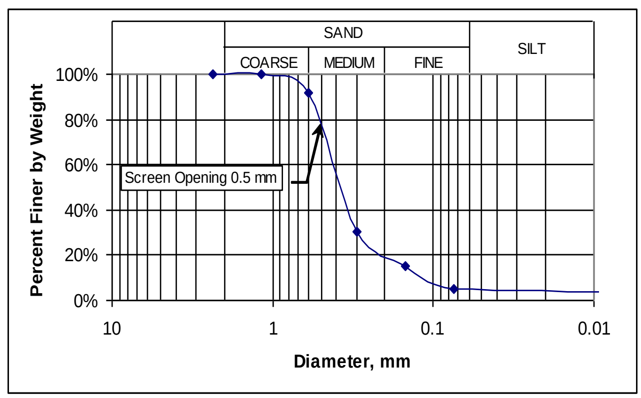

3

- Designed to provide full capture trash removal at rated flow
- Removes all debris larger than fine sand
- Captures some nutrients, metals and organic matter with debris
- Instantaneous debris removal - debris dries quickly in the all-weather debris compartment where it can be readily removed with hand tools or moving equipment
- Maintenance-free 100% stainless steel construction
- Engineered for each application and easily installed
- No moving parts
- Does not clog and will not fail


4


5

Particulate Removal
The COANDA filter removes everything larger than fine sand.




6

Legend:

1. 50-100 cfs Delhi Channel Screen in Orange County, provides regional end of pipe trash removal and non-storm low flow upstream of Newport Bay.
2. Regional channel screen, awarded Stormwater Solutions Top 10 Projects of the Year 2008.
3. Vineyard Screen, Albuquerque, NM
4. Paradise, CA Municipal Diversion
5. Side entry channel screen in McAllen, TX, for international project removing trash from tributary of the Rio Grande R.
6. 1,200 cfs AMAFCA Channel Screen near the headwaters of the Rio Grande R.

PATENTED TILTED WEDGEWIRE TECHNOLOGY
US Patent Nos. 6,705,049, 7,258,785, 7,300,590, 7,584,577 , 7,805,890
Other patents pending Nov 2012

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A waiver is justified for several reasons. First and foremost, the largest screen opening is only 1.0 mm, which is too small for mosquitoes to pass through. In addition, the plenum underneath the Coanda Screen typically discharges to an open channel at the end of the screen, which conveys treated water to a point of beneficial use. If access was needed, it could be made at that point. In other instances, instead of an open channel, a pipe is provided with manhole access at some point downstream. Third, most Coanda Channel Screens are in continuous service, treating low flows 24/7 and even during dry weather flows which are always flowing in the form non-storm runoff (urban overwatering, cooler condensate, illicit discharges, etc., sometimes referred to as "urban slobber"). This means that there is rarely or sometimes never any ponding or stagnant water downstream of the Coanda Screen. The Channel Screen support structure and plenum are designed with sloping bottoms to prevent any ponding of downstream water.

Having installed numerous Coanda Channel Screens throughout California and the US and internationally, we know of no Coanda Screen application has ever had a mosquito problem.

3.f.2 Standard Coanda Curb Inlet BMP

Depicted in Figure 3.7 is the standard configuration of the majority of Coanda Curb Inlet BMPs which have been built to date. The 1.0 mm Coanda Screen is the primary means of trash removal. No trash can fit through 1.0 mm openings. All trash entering the vault will wind up in the debris compartment, where it remains until removed by maintenance crews. The debris compartment is bounded on three sides by concrete walls, and on one by the debris fence, which has 2.0 to 4.0 mm openings. The only way debris could escape the vault would be during a flow event exceeding the Q_{1-1}, and when flow escapes the bypass openings and an excessive amount of accumulated debris is present in the debris compartment.

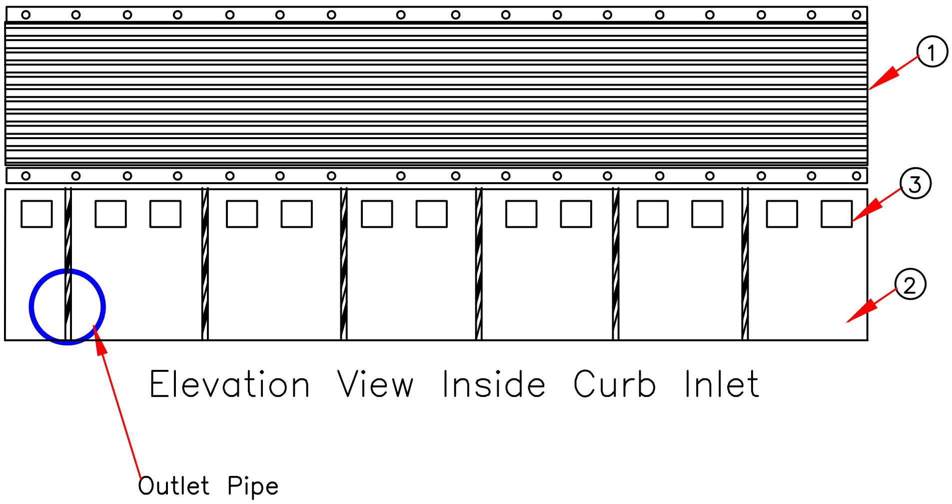
Any storm flows exceeding the capacity of the Coanda Screen can be transmitted through the Debris Fence. Should both the Coanda Screen and Debris Fence somehow become plugged, then the emergency overflow slots would convey flow out of the vault to the outlet pipe. Refer to photos of this design on Figure 3.8.

a. <u>Hydraulic Capacity</u>

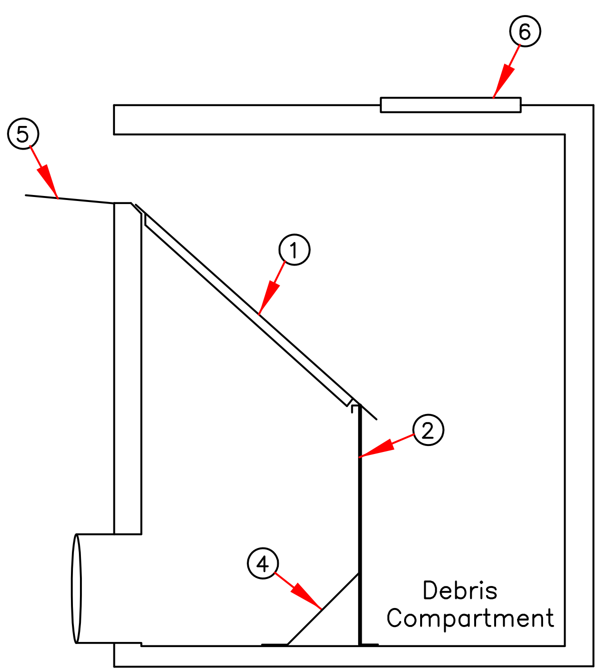
The hydraulic capacity of the Coanda Screen is determined by the methodology previously presented in this section.

b. <u>Vector Control</u>

Access for vector control inspections will be provided by means of a 4"x4" opening in that section of Coanda Screen located directly beneath the manhole of the vault. Vector Control inspectors will be able to view the area underneath the Coanda Screen by looking downward through the 4"x4" opening. A rotating cover will be provided, which swivels about a single point on the Screen, so that the cover plate can be rotated by inspectors, exposing the 4"x4" opening. The rotating cover plate has a vertical fin mounted on the top, which interacts with moving water as a straightening device, to position the cover in the proper place during a storm



Elevation View Inside Curb Inlet



Curb Inlet End View

Notes
1. Coanda Screen
2. Debris Fence
3. Overflow slots
4. Internal bracing
5. Gutter (street level)
6. Access Manhole

US Patent Nos. 6,705,049, 7,258,785, 7,300,590, 7,584,577, 7,805,890; other patents pending.

COANDA The Effect Matters	Figure 3.7 Standard Curb Inlet BMP	SEE 031621	NO SCALE

Figure 3.8

STANDARD COANDA CURB INLET BMP

THE BEST SOLUTION FOR REMOVING TRASH & DEBRIS IN CURB INLETS

The interior of typical curb inlet BMP shows the COANDA screen on the left, through which all water passes, and the large debris compartment on the right..

The COANDA Curb Inlet Filter

The patented COANDA Curb Inlet BMP is a storm water filter that employs stainless steel tilted wedge wire technology. Unlike conventional filtering devices such as bags, netting, conventional screens, storm water clarifiers, and hydrodynamic separators, this technology is designed specifically to handle high velocity and high volume flow rates associated with rapidly concentrated peak flows coming from all types of land uses. The COANDA Curb Inlet BMP is self-cleaning and non-clogging with no moving parts. Readily accessible for periodic removal of captured trash.

The COANDA Approach Plate, barely visible, fits snug against the curb inlet opening so as not to impede water flow or be exposed to traffic.

Los Angeles, CA

San Diego, CA

Fontana, CA

Vector control has never been an issue with Coanda Curb Inlet BMPs. Bacterial growth is significantly impeded because captured debris dries quickly and remains dry. No special handling techniques are required for removal of trash.

US Bureau of Reclamation Testimonial

"These screens have large flow capacities and are hydraulically self-cleaning without moving parts, so they require minimal maintenance."

Published in "Design Guidance for Coanda-Effect Screens," *Report No. R-03-03*, U.S. Dept. of Interior, Bureau of Reclamation Technical Service Center, Denver, CO, July 2003.

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event. During inspections, the cover plate can be rotated 90 to 180 degrees about the swivel point, by means of a rod or a stick or a simple tool like a screw driver, or even by hand. When rotated to the open position, the 4"x4" opening will be fully exposed for viewing the area underneath the Coanda Screen. This large of an opening should also be adequate to permit the insertion of solid or liquid pesticide products. Once the vector control inspection is complete, the cover plate is restored by simply rotating the cover back to its original position. Under normal service conditions during a rain event, the 4"x4" opening through the Coanda Screen will be fully covered by the plate.

For additional information, refer to Section 6 in this report, which contains further explanation and a drawing of a typical 4"x4" opening with rotating cover plate.

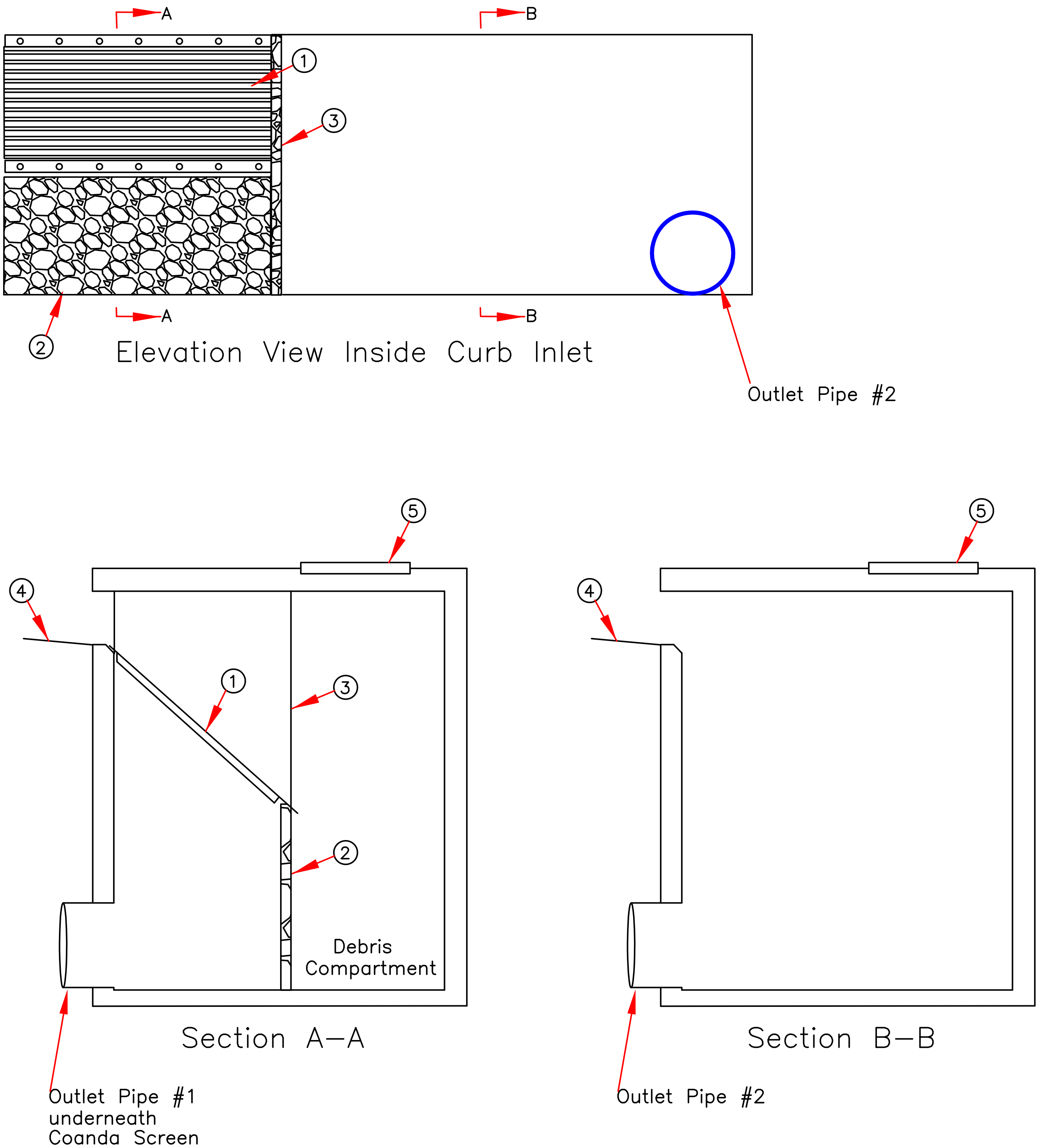
The specific methods of dealing with potential mosquitos differ slightly for each of the four configurations presented in this Update, as explained throughout Section 3, specifically in subsections 3.f.1 through 3.f.4. Also see comments in Section 3.k.

3.f.3 Partial Width Isolated Coanda Curb Inlet BMP

Depicted in Figure 3.9 is a partial width isolated Coanda Curb Inlet BMP. Drawings are shown in Figure 3.10. This configuration can be thought of as a small Coanda Channel Screen mounted inside a portion of a curb inlet vault. This configuration is similar hydraulically to the Coanda Channel Screen, but does not involve the entire vault, and the screened portion is hydraulically isolated from the rest of the vault. Two outlet pipes are provided in this configuration, one identified as Water Quality Outlet Pipe #1 for the portion of stormwater which is treated by the Coanda Screen to remove trash, the other Outlet Pipe #2 is for untreated stormwater. A solid divider wall separates the water side of these two portions of the vault. This vertical wall is made either of steel or concrete (Note 3 on Figure 3.9) to provide separation of the BMP from the rest of the vault itself. Separated debris side may or may not be isolated from the untreated portion of the vault. Where there is no separation on the debris side, some other type of BMP, perhaps a CPS device or something similar, could be installed at Outlet Pipe #2 for the purpose of removing trash from the vault. In such situations, the Coanda Screen would only be serving to treat stormwater for beneficial reuse.

Since this configuration involves only a portion of the overall vault, some flow is treated to remove trash and the remainder of the flow is not treated. In the sample calculations previously cited above, the peak flow Q_p is 12.69 cfs. The corresponding Q_{1-1} is 2.09 cfs, or roughly 16 percent of the peak flow. Thus, the portion of the vault covered by Coanda Screens would be at least 16 percent of the total length of the vault. Some other type of BMP will be needed to remove trash from the non-screened vault at Outlet Pipe #2.

One of the major applications of this configuration is employing the curb inlet vault to "scalp" part of the stormwater runoff and treat only that portion of the total to provide clean water for a range of beneficial reuse alternatives. A frequent beneficial use may be to provide clean supply water for irrigation. Creating a source of recycled water is perhaps the primary efficacy of this



Notes
1. Coanda Screen
2. Solid Screen Support Wall
3. Solid Interior Full Height Structural Isolation Wall
4. Gutter (street level)
5. Access Manhole

US Patent Nos. 6,705,049, 7,258,785, 7,300,590, 7,584,577, 7,805,890; other patents pending.

COANDA
The Effect Matters

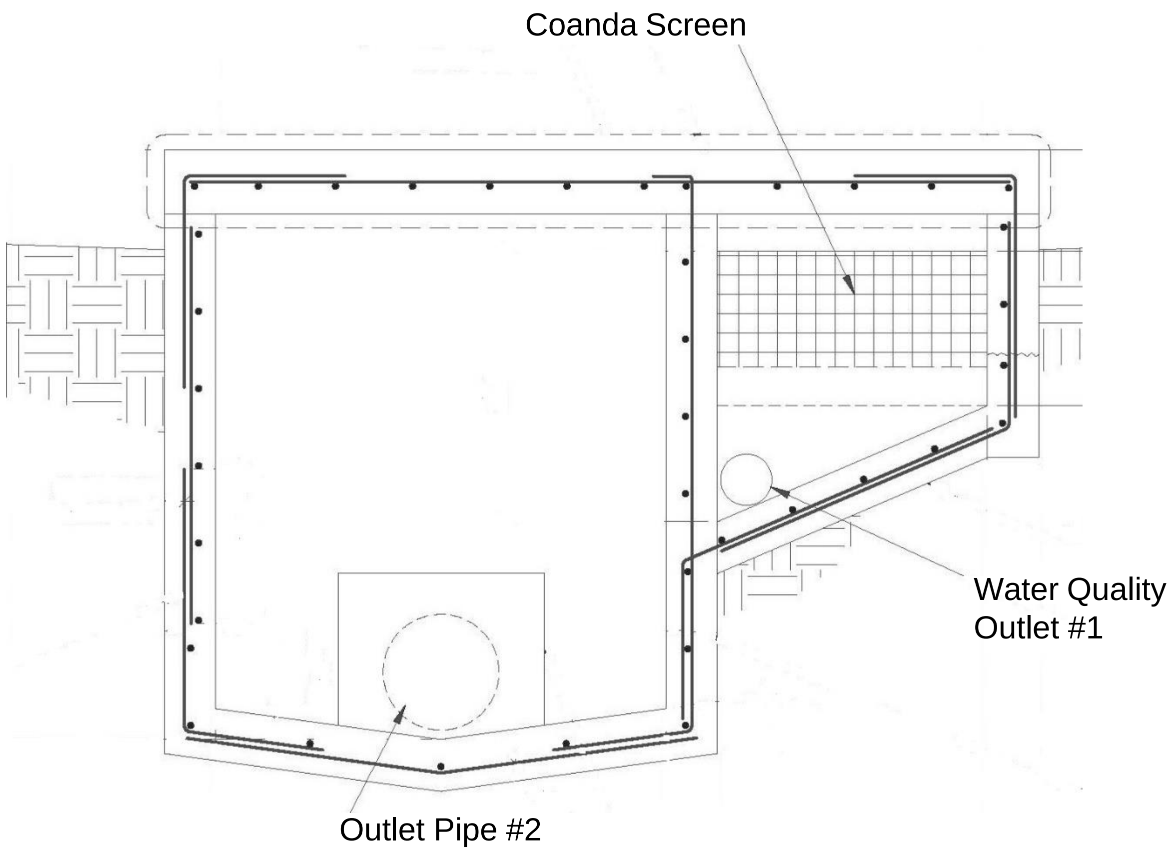
Figure 3.9 Partial Width Isolated Curb Inlet BMP

SEE 031621	NO SCALE

Figure 3.10

PARTIAL WIDTH ISOLATED COANDA CURB INLET BMP

THE BEST SOLUTION FOR REMOVING TRASH & DEBRIS IN CURB INLETS



In this configuration, a solid wall separates the BMP from the rest of the vault. It resembles a small Coanda Channel Screen built inside a portion of a curb inlet vault. The BMP itself is complete isolated hydraulically. The largest opening is 1.0 mm, which should prohibit the movement of mosquitos. There is no means of access to the plenum underneath the Coanda Screen, nor should there ever be such a need. In most other aspects, this configuration is similar to the Partial Width Open Coanda Screen Curb Inlet BMP.

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configuration. With growing interest in recycling stormwater for beneficial reuse, this configuration has applications not just in California but throughout the world. The State of California has set goals for the recycling of stormwater for beneficial reuse, and this configuration is designed to meet that need.

c. Hydraulic Capacity

The hydraulic capacity of the Coanda Screen is determined by the previous equations.

d. Vector Control

A vector control waiver for an access hatch is requested for this configuration because the same hydraulic issues exist as those involving the Coanda Channel Screen, Section 3.f.1. In this configuration, the plenum underneath the Coanda Screen is completely isolated hydraulically from the remainder of the curb inlet, and the largest opening is only 1.0 mm, which again is too small for mosquitoes to pass through. If a mosquito problem were to develop anywhere downstream, it would assuredly be unrelated to the BMP itself. And since the bottom is sloped to Water Quality Outlet Pipe #1 which originates from the plenum underneath the Coanda Screen, there is no breeding area anywhere in or near the BMP for mosquitos to acquire a habitat. More likely would be the case that a surface water impoundment somewhere downstream of the vault, fed by Water Quality Outlet Pipe #1, would be that breeding area, in which case the impoundment itself should be treated around the shoreline.

3.f.4 Partial Width Open Coanda Curb Inlet BMP

Depicted in Figure 3.11 is a partial width Open Coanda Curb Inlet BMP. Corresponding photos are shown in Figure 3.12. This configuration is quite similar to the one presented previously in Section 3.f.3, with the exception that the divider wall is not full-height but only partially divides the BMP from the remainder of the vault. An open air space would be located on one end of the Coanda Screen. Water Quality Outlet Pipe #1 is located underneath the Coanda Screen, and provides a dedicated exit point for all treated water. On the drawings, Outlet Pipe #1 is sometimes referred to as a water quality outlet pipe.

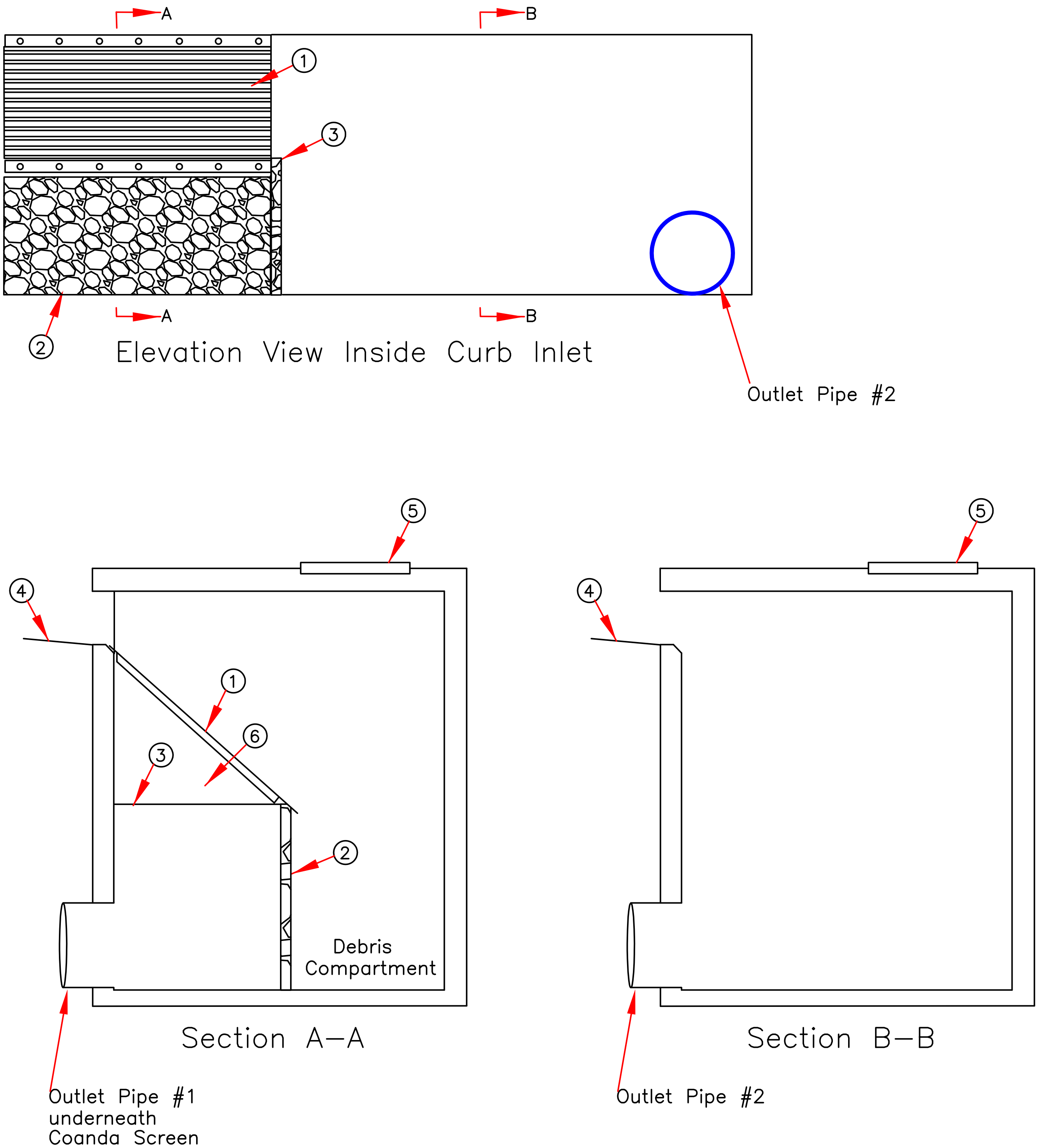
The difference between the open BMP versus the closed BMP given in the previous section is that the divider wall is half-height instead of full height. Only the air space is shared within the vault, not the water side. The similarity is that the shorter divider wall isolates treated from untreated water. Any runoff not reaching the Coanda Screen is not involved in any way with the BMP, but simply enters the vault and discharges untreated into Outlet Pipe #2.

a. Hydraulic Capacity

The hydraulic capacity of the Coanda Screen is determined by the previous equations.

b. Vector Control

A large opening is present on the open end of the Coanda Screen, through which access is readily available to the plenum underneath the screen, for the purpose of inspection or for injecting or inserting pesticides. Refer to the drawing on Figure 3.11 and the photographs on Figure 3.12.



Notes

1. Coanda Screen
2. Solid Screen Support Wall
3. Top of Solid Interior Short Structural Isolation Wall
4. Gutter (street level)
5. Access Manhole
6. Open Area between compartments

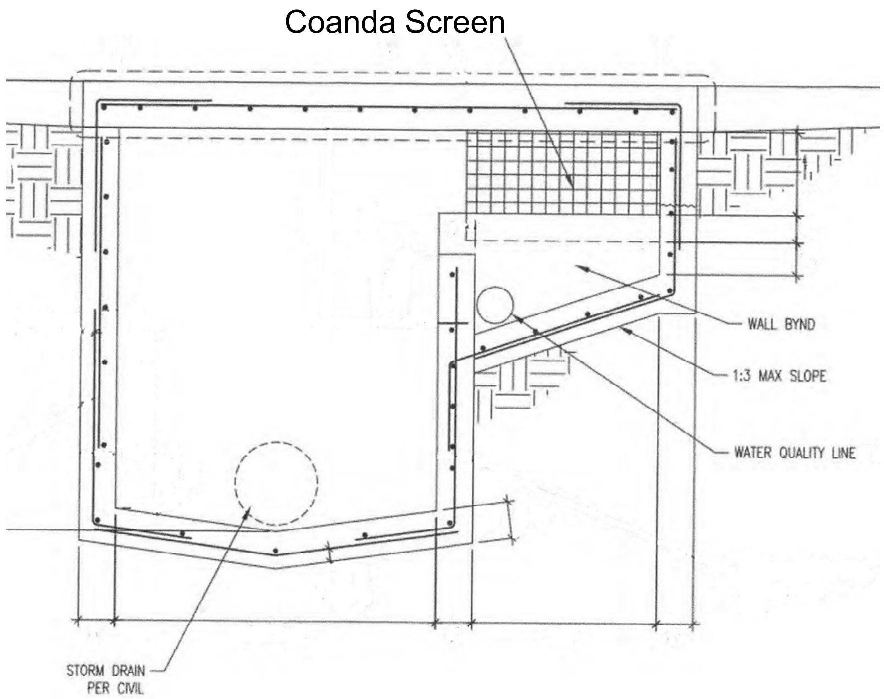
US Patent Nos. 6,705,049, 7,258,785, 7,300,590, 7,584,577, 7,805,890; other patents pending.

COANDA The Effect Matters	Figure 3.11 Partial Width Open Screen Curb Inlet BMP	SEE 031621	NO SCALE

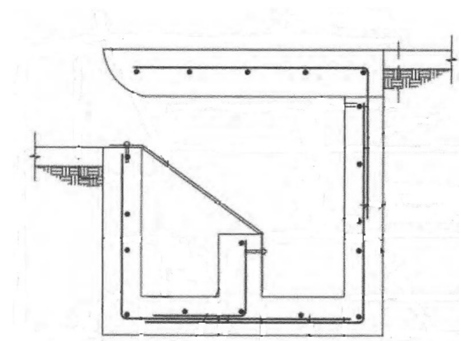
Figure 3.12

PARTIAL WIDTH OPEN COANDA CURB INLET BMP

THE BEST SOLUTION FOR REMOVING TRASH & DEBRIS IN CURB INLETS



Only a portion of the vault is equipped with the Coanda Screen. The purpose of this configuration is to remove trash from a portion of the flow, discharging to a dedicated Water Quality Line for beneficial reuse. A different type of BMP could provide trash removal for the main vault. The space at the end of the Coanda Screen is open, to facilitate the insertion of insecticides.



Section Cut View through the Coanda Screen reveals the screen is mounted to interior concrete walls rather than a Coanda debris fence.

Photographs underneath the Coanda Screen reveal the ease of access to the plenum for insertion of insecticides from street level. No personnel should ever find it necessary to enter the vault.

The Water Quality Lines deliver treated water to a beneficial reuse facility, such as an irrigation pond. There is no ponding of water anywhere in the vault. Bacterial growth is significantly impeded because captured debris dries quickly and remains dry. No special handling techniques are required for removal of trash.

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The top of the interior wall (Note 3, Figure 3.11) isolates the plenum underneath the screen from the remainder of the vault. The plenum should be visible from street level when standing over the gutter. There is no barrier to impede access to view the plenum or insert pesticides from street level. No access hatch in the screen is even necessary because the end is always open to the environment. It is noteworthy that if mosquito problems were somehow to develop downstream of the BMP in the Water Quality Outlet Pipe #1, this situation would be unrelated to the BMP itself. And since this is a Water Quality Pipe, the point of discharge is probably a lake or impoundment for irrigation supply water, where mosquito problems can be readily addressed from the shoreline.

3.f.g Internal Bypass

The internal bypass was discussed in the previous sub-sections 3.f.1 through 3.f.4. Each of the four configurations presented in in these sub-sections handles internal bypass a little differently. To summarize what has been presented earlier:

Coanda Channel Screens, discussed in Section 3.f.1, provide no internal bypass but are always designed with external bypass features that have been engineered into the overall hydraulic design of each site-specific application. Provision is always made to handle peak flows which may exceed the capacity of the Coanda Screens. In most cases, a separate dedicated downstream conveyance is provided. In other cases, the Coanda Screens may become submerged during peak flow events, thus unable to isolate trash until the peak flow has subsided and open channel flow conditions once again return to normal.

The standard Coanda Curb Inlet BMP, discussed in Section 3.c and 3.f.2, provides multiple emergency overflow slots near the top of the debris fence, which measure at least 6 inches by 6 inches each, in compliance with LA County design standards. The emergency bypass as presented in the example calculation of Section 3.c and 3.d is able to convey approximately 60 percent of the peak design flow of the vault. However, in a peak flow event, the total amount of internal bypass is shared by the flows emanating through the Coanda Screen, the debris fence, and the emergency overflow. From the Comparison Table in Section 3.d, each of these features would handle the following percentages of peak flow:

Coanda Screens	80%
Debris Fence	> 600%
Emergency Overflow	60%
Total	> 740%

The exact percentages may vary from one BMP to another. The point being, sufficient internal bypass is always provided in each Coanda Curb Inlet BMP such that there should never be any opportunity of stormwater runoff backing up onto the street. In other words, the hydraulic capacity of the BMP greatly exceeds the peak flow rate which can be conveyed through the vault itself. This question was studied and answered in the affirmative by LA County Public Works. See actual video of this scenario at the San Gabriel Test Facility at the link in footnote 8, page 7.

3.h Previously Trapped Trash

In theory, there is nothing to keep previously trapped trash from exiting the BMP under peak flow conditions via the emergency bypass. However, given the percentages of flow capacity that were just presented in Section 3.g, it would seem unlikely that previously trapped trash would ever be able to exit the BMP at all. First, the Coanda Screens in that example are removing 80 percent of the peak flow, which suggests that the bottom one-third of the debris fence is all that is necessary to convey the remaining 20 percent of peak flow. Previously trapped trash would simply stay put under this peak flow situation.

In actual practice, we do not find that previously trapped trash ever leaves the BMP until it is removed by maintenance personnel. We have additional video evidence to support this assertion, as presented in footnote 9 on page 8. Note that under peak flows, all the flow proceeds through the Coanda Screen, while virtually zero flow moves through the debris fence. Finally, we have testimonial evidence from Mr. Robbin Webber, head of stormwater maintenance for a city in Texas where Coanda Curb Inlet BMPs have been installed in a subdivision for the purpose of preventing blockages of debris in the outlet pipes downstream of the City's curb inlet vaults. After the BMPs were installed, the City no longer had any blockages. Refer to Section 8.2, under client testimonials.

In conclusion, while we acknowledge that previously trapped trash could in theory exit the BMP via the internal bypass, we do not believe it has or would. This conclusion is based upon field experience with hundreds of installations throughout our company's history.

3.i Calibration Feature

There are no moving parts in our BMPs. The hydraulic design is very robust, as has been documented in Sections 3.c, 3.d, and 3.g. That being the case there is nothing in the different configurations of the Coanda Screen design that requires calibration.

3.i Photos

Multiple photographs of each configuration are presented in Sections 3.f.1 through 3.f.4, specifically in Figures 3.6, 3.8, 3.10, and 3.12 of this Updated Fact Sheet. Coanda maintains a library of hundreds of photographs and videos of our installations. Additional photographic information can be made available upon request.

3.j Material Type

All elements of the Coanda BMPs are designed to meet California Building Code structural standards. All materials are 304 Stainless Steel. This includes the Coanda Screen, Debris Fence, anchor bolts, all structural reinforcing and other bolts and screws. Coanda, Inc. is committed to "Buy American" and has never purchased raw or fabricated steel products from any foreign country. Even in the global marketplace, we use steel only from sources within the United States and ship our finished products overseas. We have steadfastly resisted buying steel from China or other countries.

All of the structural elements of the BMP are fabricated in a workmanlike manner and welded in conformance with AWS Standards, "Welding Corrosion-Resistant Alloys: Stainless Steel," *Manual of Applied Welding Engineering: Processes, Codes, and Standards*, 2nd Ed., 2016. The installed BMP is both structurally strong and corrosion resistant. Using the same material throughout provides insurance against any long term deterioration due to galvanic corrosion.

3.k Design Life

The issue of design life is one of Coanda's greatest assets. During the nearly year-long period of testing by LA County Public Works, it became apparent that the Curb Inlet BMP would have a minimum service life of at least 10 years. The US Bureau of Reclamation recommended that the service life should be at least 20 years for planning purposes. However, USBR had already installed early versions of Coanda Screens dating back to the 1960s which are still active today. Therefore, the design life of Coanda Screens is measured not in years but decades.

In most cases, stormwater is light duty when compared to the hydroelectric power industry, which also utilizes our Coanda Screens. In December 2020, we completed a 10 year audit of a group of 11 Coanda Curb Inlet BMPs in stormwater service which were installed exactly 10 years prior. The BMPs currently look almost new and do not exhibit signs of wear and tear or inefficiency. The findings are that these inlets are:

- Fully intact
- No failures
- Nothing broken
- No cleaning of screens has ever been necessary
- No overflow or blockage has ever occurred
- The only maintenance activity has been restricted to removing trash with a Vactor truck operated by a 2-man crew for 10 minutes a total cost of $40 per cleanout.
- Cleaning performed on average twice per year.
- No one has entered these vaults in the last 10 years.

On this basis, Coanda believes that a conservative estimate of the design life of Coanda Screens in stormwater service should be on the order of 30-40 years.

Coanda Screens are generally among the highest first cost among other types of stormwater BMPs currently on the market. Yet, when the low cost of maintenance is taken into consideration, the design life cycle cost of Coanda Screens is but a small fraction of the cost of all other BMPs, the lone exception being street sweeping. Our customers fully understand this and are not purchasing Coanda Screens to save money in the current year's budget, but in order to save larger sums of money in the long term. Professional engineers who are capable of determining life cycle cost estimates have agreed with our assessment. Some have adopted a 20 year life cycle for our products and others have used different numbers, but the bottom line conclusions generally agree with the claims which we have made.

On account of this issue, besides not having a vector control problem, our company is reluctant to add hinges and hatches and removable covers to our BMPs. Once moving parts are introduced into stormwater service, then the failure rates go up and design life declines. Having no moving parts is one of the greatest features of our BMPs, to which the USBR has attested, and which we repeat here:

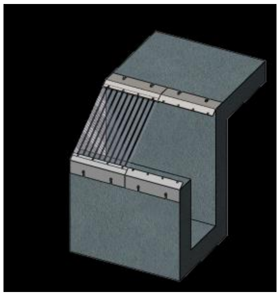
> *"These screens have large flow capacities and are hydraulically self-cleaning without moving parts, so they require minimal maintenance."*[10]

As stated previously, no mosquito problems have existed in any of our installations. But over the course of time, should it come about that mosquitos are encountered in any of our BMPs, we would be interested in assessing the cause of the problem, then assist in developing labor-saving ways to mitigate their presence. The methods for dealing with mosquitos in each of the four configurations presented in this Update have been explained earlier throughout Section 3.

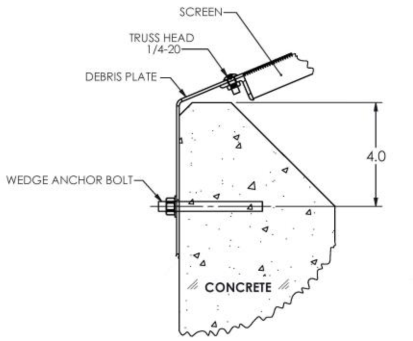
[10] Wahl, Tony L., "Design Guidance for Coanda-Effect Screens," US Department of the Interior, Bureau of Reclamation, Technical Service Center, Water Resources Research Laboratory, Denver, Colorado, Report No. R-03-03, July 2003, http://www.usbr.gov/pmts/hydraulics_lab/pubs/R/R-2003-03.pdf

4. INSTALLATION GUIDANCE

Coanda provides technical support for the installation of our BMPs free of charge to customers. We ship the Coanda Screens and debris fences along with all appurtenances necessary for the installation, so that nothing but ordinary tools are required to complete the installation process. The standard instructions given to contractors include the following steps.



1. Position Coanda Screen(s) as shown in the graphic.
   a. Be sure the painted arrows on the screens point in the direction of flow.
   b. Top plate and bottom plate should fit snugly against concrete.
2. If necessary, trim edge(s) of screen to fit snugly against the walls of the vault.
3. Drill 3/8 inch holes in the concrete through the pre-drilled holes on the top and bottom plates.
4. Clean the drill holes with the blow-out bulb.
5. Insert 3/8 inch wedge anchors and hammer into place.
6. Tighten the nuts.



[redacted] Installation *Detail*

No field welding should ever be required during installation. If any non-standard procedures are required, we always provide that information to the owner and contractor. Should problems arise during installation, we respond as quickly as possible so as to avoid any down-time issues.

Installation errors have been extremely rare. On one project in 2009-10 a contractor called with some confusion as to why the plates didn't fit, which we readily diagnosed as an attempt to mount the screens upside down. Contractor was instructed to rotate the screens 180 degrees, whereupon they discovered that the screens fit perfectly. As a result of that project, we started painting arrows on each screen, with instructions to mount the screens in the direction of the flow. Ever since that project, there have been no installation errors of this type.

More recently, a contractor attempted to install our screen in a non-standard vault that was not built to spec. The approach angle shown on the drawings did not match what the civil contractor had actually built. The screen was returned to our shop and modified to fit actual field conditions. Ever since that occasion, we make a practice of asking the installation contractor to verify field conditions against the drawings prior to attempting the installation. So far, there have been no installation errors of this type.

5. OPERATION AND MAINTENANCE INFORMATION

The Operation and Maintenance procedures for Coanda BMPs involving curb inlet vaults basically call for removal of trash twice a year or at a greater frequency when indicated by field conditions. This is typically done with a Vactor truck but can be performed using hand tools if necessary. A typical Vactor crew should be able to clean a curb inlet in about 10 minutes. The first step involves removing the manhole cover. Next, the stinger is inserted into the vault. Then, all trash is vacuumed out. When completed, the manhole cover is replaced and the truck can move to the next vault.

When Channel Screens are built, Coanda provides an O&M Manual document specific to that installation. The O&M Manual sections include Project Description, Operating Principle, Design Summary, Maintenance Requirements, Warranty, and Record Drawings.

The following section on Maintenance Requirements is taken from an actual installation.

The Coanda Screens should be cleaned and debris removed on a periodic basis. The frequency depends upon hydraulic loading and trash accumulation. Because the [redacted] Channel can continuously discharge low flows onto the Coanda Screens, there may be a need for cleaning once or twice per week. Owing to the seasonal nature and variable frequency of urban runoff, experience will become the best indicator as to when and how often routine cleaning is needed.

Captured debris should dry quickly and remain inert, either on the screen or in the debris catchment area. The [redacted] Channel receives illicit discharges from numerous sources, including dry weather non-storm runoff, cooling water condensate, irrigation overflows, etc. These illicit discharges could pose a nuisance and could keep captured debris moist for periods of time.

There should be no need for maintenance personnel to have direct contact with captured debris. If this occurs and persists, contact the manufacturer. There are many options for cleaning, as described below.

Debris removal and cleaning can be carried out within a few minutes using ordinary hand tools. The tools most helpful are:

1. *Square-blade scoop*
    a. *Long handle*
    b. *Short handle*
2. *Straw brooms*
3. *Wheel barrows*
4. *Metal dust pans*

In addition, a small Bobcat with a scoop could be used to collect trash from the debris catchment area. When using this type of equipment, the trash should be placed in a trash bin or vehicle suitable for hauling trash on public streets.

Cleaning can be accomplished with a Vactor truck. An access ramp was provided for this purpose.

Cleaning can also be accomplished using a pressure washer.

When carrying out a cleaning operation, observe the following guidelines:

1. *Work in teams of two or more persons.*
2. *Do not enter the debris catchment area during or immediately after storm events. The* [redacted] *Channel is vulnerable to rising water which is concentrated during storm events. Consequently, the onset of flood stage can be experienced with little or no warning.*
3. *Maintenance personnel should wear long sleeve shirt, full length pants, gloves and a hat.*
4. *When possible, and in the interest of safety, park all vehicles outside the debris catchment area, not blocking the ramp.*
5. *Limit public access during cleaning operations, and avoid pedestrian movement around work areas.*
6. *Should there be any debris on top of the Coanda screen, brush it off with a soft bristled broom or use a pressure washer. Do not put steel tools in direct contact with the Coanda Screen, to avoid damage such as pitting or scoring.*
7. *Collect all trash and debris into plastic bags or containers.*
8. *If animals are found, notify Animal Control.*
9. *Note any unusual conditions and do not attempt to remove anything except ordinary trash and debris.*
10. *If there has been any damage to the Coanda screen, contact the manufacturer immediately.*

There should be no need for deferred maintenance in any of our installations. The possible exception might be the rotating cover plate that will be provided for conducting inspections underneath the Coanda Screen, and which applies only to the Standard Coanda Curb Inlet BMP, Section 3.f.2. This being the only part of the BMP that is not welded or bolted, it is conceivable that this element might become weak or damaged over time simply because it is a moving part, in the worst case leaving a 4"x4" opening exposed to storm runoff events. If that should ever happen, either vector control personnel or maintenance personnel or whoever discovers the problem should contact the manufacturer, who can ship another rotating cover to be installed in the field using ordinary hand tools. Two crescent wrenches are the only tools that are required to install the cover plate.

If a screen should ever be found in need of repair, a new screen can be fabricated and shipped to the field as a replacement. There was one instance of an isolated portion of screen in Northern California had been intentionally vandalized, according to the client. Partly for this reason, we typically fabricate large screen projects using small abutting sections of adjacent screen This way, if only one section gets damaged, there is no need to replace anything but the one small section. When the new section of screen is shipped to the site, it can be inserted simply by removing the bolts, inserting the new section of screen, and re-tightening the bolts. If an anchor bolt should be damaged, it can be cut-off flush with the concrete, with a new anchor bolt inserted in its place.

6. VECTOR CONTROL ACCESSIBILITY

This report is being submitted to MVAC at the same time it is transmitted to the State Water Resources Control Board. Coanda has also had prior discussions with MVAC members over a period of 5 or more years concerning vector control issues. We have attended meetings to discuss vector control issues with MVAC members, to respond to their concerns, and explain how our products provide a barrier to mosquito movement. Refer to the MVCAC verification letter, dated September 7, 2021, in Appendix E.

The discussions as to how vector control personnel are able to access the BMP have been presented for each of the four configurations developed earlier in this Update, in Sections 3.f.1 through 3.f.4. The details are in those sections, but a general summary of the recommendations is presented below.

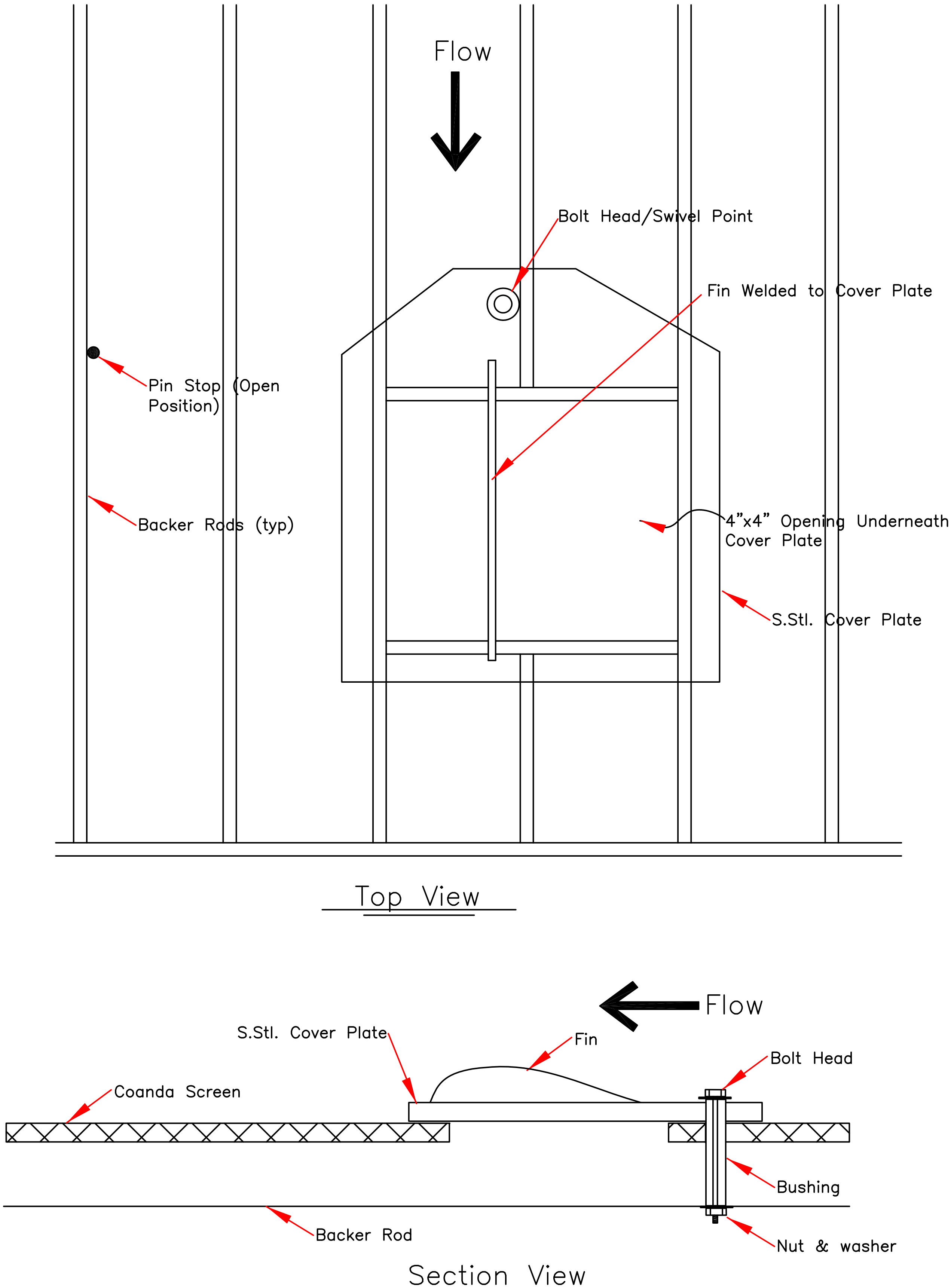
Coanda Channel Screen BMP (Described in Section 3.f.1)
There is no need to access the plenum underneath the Coanda Screen. The largest opening in the entire BMP is 1.0 mm, which is too small for mosquitos.

Standard Coanda Curb Inlet BMP (Described in Section 3.f.2)
Access for vector control purposes is provided through a 4"x4" inspection port on the face of the Coanda Screen. This opening will be provided in that section of Coanda Screen which is located directly beneath the manhole of the vault. Vector Control inspectors will be able to view the area underneath the Coanda Screen, unimpeded and unobstructed, simply by looking downward.

A rotating cover plate will be provided, which swivels about a single point. The cover plate can be rotated by inspectors, fully exposing the 4"x4" opening. The rotating cover plate comes with a vertical fin welded to the top of the plate, which interacts with moving water as a straightening device, to keep the cover plate in proper alignment during a storm event. Refer to the drawing of the Vector Control Cover Plate, presented in Figure 6.1.

The cover plate can be freely rotated about the swivel point, by means of a rod or a stick or a simple tool like a screw driver, or even by hand. A pin stop will be welded to the Coanda Screen on which the plate can rest. This pin stop secures the cover plate in the "open" position during inspections. At the beginning of a vector control inspection, the inspector will rotate the cover plate to the "open" position, fully exposing the 4"x4" opening for viewing the area underneath the Coanda Screen. This large of an opening should also be adequate to permit the insertion of solid or liquid pesticide products. Once the vector control inspection is complete, the cover plate is restored by simply rotating the cover back to its original position. Thus, under normal service conditions during a rain event, the 4"x4" opening in the Coanda Screen will be fully covered by the plate.

With the cover plate rotated to the "open" position, the 4"x4" inspection port should be fully exposed to the full view of an inspector while standing directly above the manhole looking



Note: All materials shown are 304 Stainless Steel

COANDA The Effect Matters	**Figure 6.1 Vector Control Cover Plate**	SEE 080521	NO SCALE

downward. Illumination using a hand-held flashlight or a hand-held mirror may be helpful, so that the area underneath the screen is exposed for viewing. Vector Control personnel may also utilize the inspection port to insert solid or liquid pesticide.

Before leaving the site, Vector Control personnel should restore the cover plate by simply rotating it back into place.

There are no moving parts anywhere in the Coanda Screen installation except for the rotating cover plate, and this element is applicable only to the Standard Coanda Curb Inlet BMP, Section 3.f.2. The cover plate being the only part of the BMP that is not welded or bolted, it is conceivable that this element might become weak or damaged over time because it is a moving part, in the worst case leaving a 4"x4" opening exposed to storm runoff events. If that ever happens, either vector control personnel or maintenance personnel or whoever discovers the problem should contact the manufacturer, who can ship another rotating cover to be installed in the field using ordinary hand tools. Two crescent wrenches are all the tools that are necessary to replace the cover plate.

The pin stop shown on Figure 6.1 is an unobtrusive short stainless steel pin sticking up a fraction of an inch (about 1/2 inch) above the Coanda Screen. Its sole purpose is to provide a resting point for the cover plate in order to hold it in the "open" position during an inspection. The pin stop may include an integral fin or a smooth plate welded to the pin so as to deflect any debris or trash over the top of the pin and prevent it from snagging debris or trash.

Partial Width Isolated Curb Inlet BMP (Described in Section 3.f.3)
Like the Coanda Channel Screen BMP above, there is no need access the plenum underneath the Coanda Screen. The largest opening in the entire BMP is 1.0 mm, which is too small for mosquitos.

Partial Width Open Curb Inlet BMP (Described in Section 3.f.4)
Access for vector control purposes is provided by a large opening on the end of the Coanda Screen. This opening is large enough to view conditions in the plenum underneath the screen, and/or to insert pesticide products.

7. RELIABILITY INFORMATION

7.a Estimated Design Life of Device
Please refer to Section 3.k where this subject was previously addressed.

7.b Warranty Information
Coanda will warranty all materials for two years following installation. The only exception is that there is no evidence of vandalism, intentional abuse, or an unforeseen event.

7.c Customer Support Information
Warranty service and post-warranty service is available through Coanda, Inc. in Irvine, CA, or our business partner in Denver, CO. Contact information is as follows:

Attn: Steven E. Esmond, PE
Coanda, Inc.
3943 Irvine Blvd., #327
Irvine, CA 92602
www.coanda.com
P: (714) 389-2113
C: (714) 272-1997
sesmond@coanda.com

Attn: Robert K. Weir, PE
Hydroscreen Co., LLC
2390 Forest St.
Denver, CO 80207
http://www.hydroscreen.com
P: (303) 333-6071
C: (303) 919-9165
rkweir@aol.com

8. FIELD / LAB TESTING INFORMATION AND ANALYSIS

8.1 Testing Information Demonstrating Functionality and Performance

A wealth of test data on Coanda Screens is available from the US Bureau of Reclamation. This Federal agency operates a technical center and wet laboratory in Denver, CO, and has tested Coanda Screens extensively over the last two decades. USBR also publishes a public domain computer program for use in sizing Coanda Screens. They have built full scale models in order to simulate the performance of full scale facilities. Any number of publications is available, but the following one may be generally informative. See Appendix A: Tony Wahl, US Bureau of Reclamation, "Hydraulic Performance of Coanda-Effect Screens," *Journal of Hydraulic Engineering*, Vol 127, No. 6, June, 2001. ASCE, ISSN 0733-9429/01/0006-0480–0488, Paper No. 22449.

The LA County Department of Public Works operates a full scale curb inlet BMP testing facility at San Gabriel Dam. Coanda Screens were extensively tested by LA County personnel during 2011 resulting in several reports documenting the performance of the Coanda BMP. A summary report was produced for submission to the LA Regional Board and is contained in Appendix B: LA Regional Board Certification of Coanda Screens as a Full Capture Device, dated 11/15/2011, along with the technical report submittal package.

The University of Texas built a full scale test facility utilizing Coanda Screens to study the Coanda Effect, and measure velocities through individual openings in real time. A 3D computer model was also developed. This research provided validation to support the claims for the self-cleaning property of Coanda Screens. Refer to Appendix C: Jungseok Ho, Joseph Prado, and Lizbeth Orduno, "Coanda-Effect Screen Velocity Monitoring Using particle image Velocimetry," slides from a technical paper presented EWRI ASCE LID Conference, January 2015, Houston, TX. This presentation is the summary of a Ph.D. dissertation which came from this research.

Coanda Screens are designed to remove trash and debris, however, nutrients and a number of other pollutants are known to adsorb onto particulate matter. The removal of nutrients through Coanda Screens has been studied in Melbourne, Australia; also by the University of Southern California; also by the City of Rowlett, Texas; also by Texas A&M University Civil Engineering Department, summarized in a masters thesis on the topic of nutrient removal in Coanda Screens. Contained in Appendix D is a paper summarizing all of these studies, authored by Steven E. Esmond and Robert K. Weir, "Nutrient Removal Using Coanda Screens," Presented at StormCon 2018, Denver CO, August 15, 2018, Session B64.

8.2 Client Testimonials

Coanda has an outstanding track record because of our superior product, as well as a high level of client service. We receive glowing testimonials come many of our clients, some of which are listed below.

"These screens have large flow capacities and are hydraulically self-cleaning without moving parts, so they require minimal maintenance." Reference: Tony Wahl, "Design Guidance for Coanda-Effect Screens," Report No. R-03-03, U.S. Department of the Interior, Bureau of Reclamation Technical Service Center, Water Resources Services, Denver, Colorado, July 2003. Phone: (303) 445-2155.

"We used to have line blockages in our drainage pipes, caused by debris. After installing Coanda screens, we've had zero blockages." Reference: Robbin Webber, Director & Chief Superintendent, City of Rowlett, Texas (972) 463-3913, rwebber@rowlett.com. Mr. Webber co-authored a conference paper for StormCon describing the overall performance and success of the Coanda Curb Inlet BMPs in his city. A copy of Mr. Webber's technical paper is appended to the end of this proposal.

"Your filter works great. We haven't seen a spec of debris in that tube, thanks to your Coanda filter." Reference: Phil and Marc de Faye, email dated August 16, 2011, Seattle, Washington, (206) 523-4855, defayepj@comcast.net.

"We were just talking yesterday about how the grass screen is about the only thing that has worked as well as we hoped." Reference: Dick Botke, Senior Vice President, PW Environmental, email dated August 17, 2011, Santa Paula, Calfornia, (805) 525-5563, dick@pwenvironmental.com.

"The Coanda screens do a great job of removing trash, debris, and sediment, and are easy to clean." Reference: Kevin Daggett, P.E., P.S., Albuquerque Metropolitan Arroyo Flood Control Authority, (505) 884-2215, kdaggett@amafca.org. AMAFCA has three channel screens, one 50 cfs, another 800 cfs, another 1,250 cfs. Mr. Daggett published a paper about AMAFCA's good experience with Coanda screens entitled, "Next Generation In-Line Structural BMPs," at the 13th Annual EPA MS4 Conference, July 2011. He and his supervisor, Jerry Lovato, P.E., published a paper entitled, "Water Quality? I Thought It Was a Cheese Grater," at StormCon, August 2012, and published in Stormwater Magazine in 2013. The paper may be accessed online through the following link: Kevin Daggett and Jerry Lovato, "Water Quality? I Thought It Was A Cheese Grater," Jan/Feb 2013 Issue, http://www.stormh2o.com/SW/articles/19793.aspx.

"The Coanda screen has kept debris out of the pipeline between our storage reservoirs, it works well and has served its intended purpose." Reference: Neil Essila, District Engineer, Paradise Irrigation District, Paradise, California, (530) 876-2037. (Built in 2007.)

"The Coanda screen does a great job, the only issue which we've had would be moss clinging to the screen at high flow rates, but the moss went through the screen after the flow subsided." His District operates a 125 cfs Coanda channel screen in Odell, Oregon. Reference: John Buckley, District Manager, East Fork Irrigation District, (541) 354-1185.

"We're surprised by how small solids are captured by the Coanda screen. It's capturing everything of concern. We had expected enough solids capture to have to replace the downstream filter at least weekly, but based on the Coanda screen's performance so far, the fine filter might have to be changed only semi-annually." (This is an industrial wastewater application.) Reference: Dave Belasco, Property Prep, in an email dated October 1, 2011, (714) 420-1190, belascodave@sbcglobal.net.

"The (Coanda screen) device can be installed in existing catch basins, but does not require confined space entry during routine maintenance." Reference: LA County Department of Public Works, *Evaluation Report*, March 28, 2011.

"The (Coanda screen) device will reduce trash and turbidity caused by particles greater than 0.5 mm. Reduction of iron, zinc, COD, BOD, total organic carbon, and nitrates were shown to be possible secondary benefits." Reference: LA County Department of Public Works, *Evaluation Report*, March 28, 2011.

Hundreds of downspouts and detention pond screens have been installed in California, Colorado and other states, with customers in major cities, Colorado Department of Transportation, US Bureau of Reclamation (USBR), US Forest Service, and US Bureau of Land Management.

American Integrated Services also has many clients who are happy to serve as references for the work that AIS has done for them. Among them are:

Mr. Chris Knoche, Brown and Caldwell, (714) 689-4836. *Modifications/Repairs of Stormwater Catch Basins*, CALTRANS State Route 73, Orange County, CA. This project involved modifications and repairs of storm water catch basins on Caltrans SR 73 in Orange County, CA. Key features of the work consisted of:

- Major modifications and repairs to storm drain catch basins, piping and culverts to provide for proper drainage;
- Concrete work to repair erosion damage;
- Re-grading of earthen basins to provide for proper drainage; and
- Strict adherence to health and safety standards, applicable to all site activities.

Ms. Beth McDonnough, (626) 568-5915. The Broadus Elementary School Storm Water BMP Installation Project, Pacoima, CA. This project involved the installation of HDPE storm water infiltration units beneath a school playground, which was finished to become the playground and a soccer field. Key features of the project included:

- Fast-track schedule to accommodate LAUSD Proposition BB construction;

- Storm water BMP installation in between several precipitation events;
- Installation of infiltration treatment unit for stormwater runoff from paved areas of elementary school.

Mr. Bryan Stone, Geomatrix Consultants, Inc., (949) 623-4700. This project involved constructing a remediation system at the former Douglas Aircraft Plant A, located at the Santa Monica Airport. Key features of the project included:

- Installation of three SVE wellhead connections;
- Installation of five SVE and two spare underground and one above grade (roof) vapor conveyance piping systems;
- Installation of two 3,000 pound activated carbon vessels and one 360 gallon above ground holding tank.
- Implemented storm water management, dust control and VOC monitoring.
- The work was completed with minimal disruption to on site businesses or the airport.
- The work was completed on time with no health and safety incidents.

Appendix A

Tony Wahl, US Bureau of Reclamation, “Hydraulic Performance of Coanda-Effect Screens,” *Journal of Hydraulic Engineering*, Vol 127, No. 6, June, 2001. ASCE, ISSN 0733-9429/01/0006-0480–0488, Paper No. 22449.

HYDRAULIC PERFORMANCE OF COANDA-EFFECT SCREENS

By Tony L. Wahl,[1] P.E., Member, ASCE

ABSTRACT: A theoretically based computational model is presented for predicting the hydraulic performance of Coanda-effect screens. These screens use a tilted-wire, wedge-wire screen panel to remove thin layers of high-velocity flow from the bottom edge of a supercritical flow. Typical slot openings are 1 mm or less, and the screens are self-cleaning with no moving parts. The discharge characteristics of several screen materials were evaluated in laboratory tests, and a relation was developed for computing the discharge through a tilted-wire screening surface as a function of the Froude number, the specific energy, and the Reynolds and Weber numbers. A model for the performance of complete Coanda-effect screen structures predicts the wetted length of screen required to accept a given flow, or the flow rate through the screen and the bypass flow over a screen that does not accept all of the flow. Predictions from the model compare favorably to results from clean-water laboratory tests of several different prototype-size screen structures. The model will allow designers to accurately size screens and evaluate design alternatives.

INTRODUCTION

There is a growing need on water resources projects to screen fine debris and small aquatic organisms from delivered flows. Unfortunately, with traditional screen designs, as the target of the screening effort becomes smaller, maintenance effort needed to keep screens clean is often dramatically increased and screen structures must be enlarged to keep through-screen velocities low. One screen design that offers potential for economically screening fine materials with a minimum of cleaning maintenance is the Coanda-effect screen, also known as the static inclined screen or sieve bend. Sieve bends have been used in the mining industry since about 1955 (Fontein 1965). Recently, this self-cleaning screen with no moving parts has been successfully used for debris and fish exclusion on several water resources projects [e.g., Strong and Ott (1988)], but there has been little detailed technical information available to hydraulic designers. Coanda-effect screens are commercially available, and manufacturers have cited screening capacities of 0.09–0.14 m^3/s/m (1.0–1.5 ft^3/s/ft) of crest length, but much higher capacities have been observed in some prototype installations. Some aspects of the commercially available designs have been patented [H. E. Finch and J. J. Strong, ''Self-cleaning screen,'' U.S. Patent No. 4,415,462 (1983)].

The primary features of a Coanda-effect screen are illustrated in Fig. 1. The screen is installed on the downstream face of an overflow weir. Flow passes over an acceleration plate, and then across the wedge-wire screen panel. Wires are horizontal, perpendicular to the flow across the screen. The acceleration plate can be an ogee-shaped profile or a simple circular arc; the objective is to provide a smooth acceleration of the flow and deliver it tangent to the screen surface at the upstream edge. Typically, the screen panel is a concave arc with a radius of curvature of approximately 3 m, although planar screen panels can also be used. Flow passing through the screen (screened flow) is collected in a conveyance channel beneath the screen, while overflow, fish, and debris pass off the downstream end of the screen. Flow velocities across the screen are typically 2–3 m/s (6.5–10 ft/s), increasing toward the toe of the screen. Froude numbers across the screen surface can vary from about 2 to 30 or greater, with the largest Froude numbers obtained when there is minimal bypass flow, or overflow, off the toe of the screen, and thus shallow flow depths and high velocities at the screen toe. Commercially available designs typically have the screen inclined at 60° from horizontal at the upstream edge, and have a total head drop across the structure of about 1.2–1.5 m (4–5 ft).

Coanda-effect screens utilize a unique tilted-wire screen panel. The individual wires are tilted a few degrees downstream (Fig. 1) to produce shearing offsets into the flow above the screen. The typical tilt angle is 5°, but angles of 3° to 6° are available from most screen manufacturers. Slot widths are typically 1 mm (0.04 in.) or less. The shearing action is enhanced by the fact that flow remains attached to the top surface of each wire, and is thus directed into the offset created at the next downstream wire. This attachment of the flow to the top surface of each wire is an example of the Coanda effect, the tendency of a fluid jet to remain attached to a solid flow boundary. A detailed discussion of the Coanda effect and its application to tilted-wire screens is provided by Wahl (1995).

MODELING FLOW OVER COANDA-EFFECT SCREEN STRUCTURE

A significant obstacle to application of Coanda-effect screens has been the inability to accurately predict the flow capacity of specific screen designs. The objective of the model presented here is to predict the discharge through the screen and the overflow off the screen; these are the variables of primary interest in most water resources applications. Because

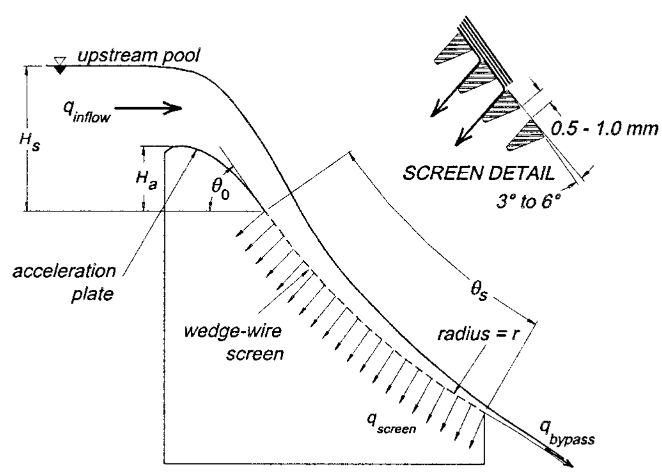


FIG. 1. Features, Typical Arrangement, and Design Parameters for Coanda-Effect Screens

[1]Hydr. Engr., U.S. Bureau of Reclamation, Water Resour. Res. Lab., Mail Code D-8560, P.O. Box 25007, Denver, CO 80225-0007. E-mail: twahl@do.usbr.gov

Note. Discussion open until November 1, 2001. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on August 22, 2000; revised January 18, 2001. This paper is part of the ***Journal of Hydraulic Engineering***, Vol. 127, No. 6, June, 2001. ©ASCE, ISSN 0733-9429/01/0006-0480–0488/$8.00 + $.50 per page. Paper No. 22449.

these screens are substantially self-cleaning, the first effort has been to develop a model applicable to clean screens.

Fig. 2 shows details of the screen material. The wire tilt angle is designated by ϕ, while w and s are the wire and slot widths, respectively. The effective height of the offset created at the leading edge of each wire is

$$y_{off} = (s + w \cos \phi)\sin \phi \quad (1)$$

or, if the tilt angle is relatively small ($\phi \leq 7°$), y_{off} can be approximated within 1% as $(w + s)\phi$, with ϕ expressed in radians. Coanda-effect screens should be constructed using a wire whose upstream edges are sharp; a rounded edge will reduce the effectiveness of the shearing offset.

Flow over a Coanda-effect screen structure is spatially varied with decreasing discharge, and can be modeled using the energy equation, accounting for the changing discharge along the length of the screen (Chow 1959). Referring to the control volume in Fig. 2, the energy equation is

$$(s + w)\theta + D_1 \cos \theta + \alpha \frac{V_1^2}{2g} = D_2 \cos \theta + \alpha \frac{V_2^2}{2g} + S_f(s + w) \quad (2)$$

where θ = inclination angle of the screen panel; α = energy coefficient (hereafter assumed to be 1.0); D_1 and D_2 = flow depths normal to the screen face; V_1 and V_2 = flow velocities; g = acceleration of gravity; and S_f = friction slope. Eq. (2) can be rearranged to obtain

$$D_2 = (s + w)\tan \theta + D_1 + \alpha \frac{(q_1^2/D_1^2 - q_2^2/D_2^2)}{2g \cos \theta} - S_f \frac{s + w}{\cos \theta} \quad (3)$$

where q_1 and q_2 = unit discharges at the upstream edges of two adjacent wires. The discharge at the downstream wire is $q_2 = q_1 - \Delta q$, where Δq is the discharge through the slot. Choosing an appropriate friction model for computation of S_f and assuming that Δq can be determined separately, (3) can be solved numerically for D_2.

DISCHARGE THROUGH TILTED-WIRE SCREENS

To implement the model described above, a relation for Δq is needed. The discharge through isolated floor slots in subcritical and supercritical flows has been studied by several investigators [e.g., Venkataraman (1977), Nasser et al. (1980), and Ramamurthy et al. (1994)]. These investigators related the discharge coefficient of the slot to the Froude number or quantities related to the Froude number. None of these studies considered the effects of an offset into the flow. Flows over and through screens installed in the floor of a conveyance channel have been studied by Noseda (1955), Miao (1958), and Babb and Schlenker (1999). Miao noted that friction could be neglected when modeling the flow profile over a mesh screen, since the flow removed by the screen prevents development of a normal boundary layer and flow profile. Babb and Schlenker studied supercritical flows over perforated plate screens used in fish separation facilities and found that the discharge coefficient could be approximated by a power curve function of the Froude number F for flows between $\mathsf{F} = 1.2$ and $\mathsf{F} = 10$.

Fontein (1965) identified gravitational, viscous, and surface tension forces, as well as air entrainment and wire shape as significant factors affecting the discharge through sieve bends used for dewatering mining slurries. Fontein evaluated the effects of the Froude and Reynolds numbers quantitatively, and the effect of the Weber number was evaluated qualitatively in tests of clean and greased-surface screens. Debris exclusion performance was affected by viscous forces and was thus a function of the Reynolds number R. To maintain self-cleaning, Fontein recommended $\mathsf{R} > 1{,}000$, with $\mathsf{R} = Vs/\nu$, where V is the velocity across the screen, s is the slot width, and ν is the kinematic viscosity.

For the present study, the discharge through each slot of a tilted-wire screen was modeled by considering Fig. 3, showing a velocity vector approaching a single slot opening. The resultant vector $\mathbf{V}_r$ is made up of the component tangent to the screen surface V and the potential velocity normal to the screen surface due to hydrostatic pressure and streamline curvature $[2g(D \cos \theta + V^2D/(gr))]^{1/2}$, where r is the radius of curvature of the screen. For planar screens, $D \cos \theta$ is the hydrostatic pressure head at the screen face, and for curved screens, $V^2D/(gr)$ is the change in pressure head caused by streamline curvature (positive for concave screens, negative for convex screens). Recognizing that the specific energy is $E = \alpha V^2/(2g) + D \cos \theta + V^2D/(gr)$, with $\alpha = 1.0$ for accelerating flows, the magnitude of $\mathbf{V}_r$ is

$$\mathbf{V}_r = \sqrt{V^2 + 2g(D \cos \theta + V^2D/(gr))} = \sqrt{2gE} \quad (4)$$

The deviation of $\mathbf{V}_r$ from the tangential direction (i.e., from a line through the leading edge of each wire) is the angle δ in Fig. 3, and can be computed from

$$\delta = \tan^{-1}(\sqrt{2g(D \cos \theta + V^2D/gr)}/V) \quad (5)$$

which can also be expressed in terms of the Froude number modified to include the effects of streamline curvature $\mathsf{F} = V/[g(D \cos \theta + V^2D/(gr))]^{1/2}$, as

$$\delta = \tan^{-1}(\sqrt{2}/\mathsf{F}) \quad (6)$$

The opening between two wires is shown in Fig. 4. The opening consists of both the width of the slot and the height

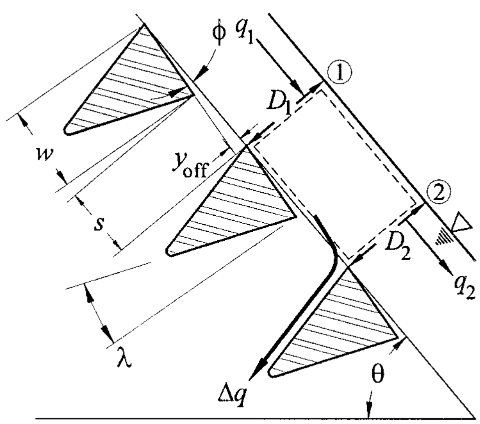


FIG. 2. Screen Geometry and Control Volume for Analysis of Flow through Tilted-Wire Screen

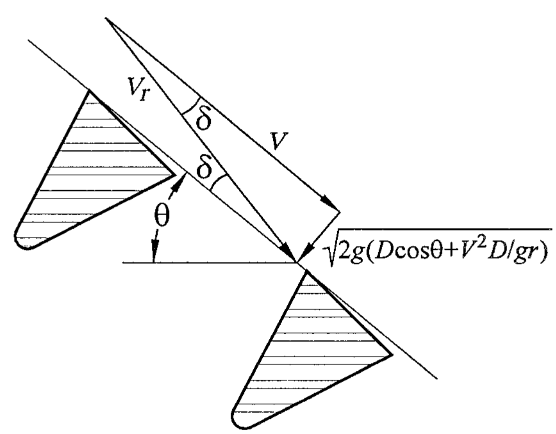


FIG. 3. Velocity Vector Approaching Tilted-Wire Screen

of the offset created by the tilting of the wires. The length of line AB is the effective length of the slot $s' = (s^2 + y_{\text{off}}^2)^{1/2}$. The deviation of line AB from a line tangent to the screen face is the angle ψ, and the deviation from a line parallel to the top edge of a given wire is ϵ. The value of ψ can be determined by noting that $\epsilon = \psi + \phi$ and $\epsilon = \tan^{-1}(y_{\text{off}}/s)$.

Fig. 5 shows the velocity vector $\mathbf{V}_r$ and the slot opening. The angle between the two is $\delta + \psi$, and the flow rate through the opening can be computed from

$$\Delta q = C_{cv} s' \mathbf{V}_r \sin(\delta + \psi) \tag{7}$$

where C_{cv} = coefficient that accounts for the effects of velocity reduction and contraction of the flow through the slot. Recalling that $\psi = \epsilon - \phi$, making use of trigonometric identities, and substituting (6) for δ, one can show that

$$\sin(\delta + \psi) = \sqrt{\frac{2}{2 + \mathsf{F}^2}} \cos(\epsilon - \phi) + \sqrt{\frac{\mathsf{F}^2}{2 + \mathsf{F}^2}} \sin(\epsilon - \phi) \tag{8}$$

For a given screen material, $\epsilon - \phi$ is constant, so $\sin(\delta + \psi)$ is solely a function of the Froude number. If one denotes this expression as C_{F} one can rewrite (7) as

$$\Delta q = C_{cv} C_{\mathsf{F}} s' \sqrt{2gE} \tag{9}$$

which has the familiar form of the equation for discharge through an orifice, when one considers the quantity $C_{cv}C_{\mathsf{F}}$ to be equivalent to a discharge coefficient C_d. In the traditional orifice equation the discharge coefficient is composed of the product of a separate velocity coefficient and contraction coefficient, and one could argue that there should be separate coefficients in (9). However, it was not possible in the current study to isolate the contraction and velocity-reduction effects, so both effects are represented in the C_{cv} coefficient.

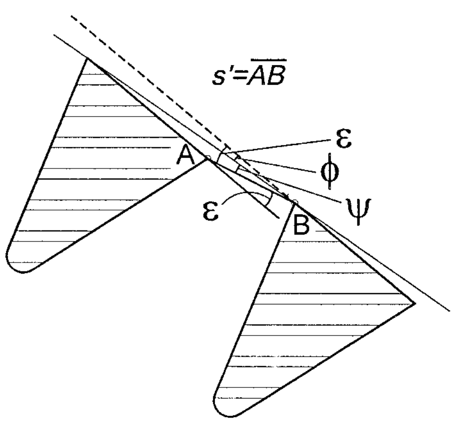


FIG. 4. Screen Slot Geometry

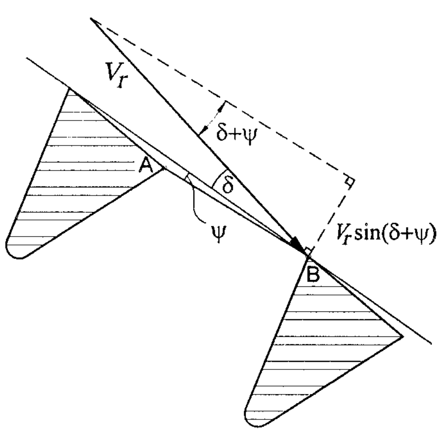


FIG. 5. Approach Velocity Vector and Screen Slot

Variation of C_{F}

The physical meaning of the $2/(2 + \mathsf{F}^2)$ and $\mathsf{F}^2/(2 + \mathsf{F}^2)$ terms in (8) can be better understood by substituting the Froude number $\mathsf{F} = V/(gD \cos \theta)^{1/2}$ into the specific energy equation (neglecting the terms associated with streamline curvature for simplicity)

$$E = D \cos \theta + \frac{V^2}{2g} = D \cos \theta + \frac{\mathsf{F}^2 gD \cos \theta}{2g}$$

$$= D \cos \theta \left(1 + \frac{\mathsf{F}^2}{2}\right) \tag{10a}$$

$$D \cos \theta = E \left(\frac{2}{2 + \mathsf{F}^2}\right) \tag{10b}$$

This shows that $2/(2 + \mathsf{F}^2)$ is the depth-energy fraction, the fraction of the total specific energy associated with the flow depth (and the change in pressure due to streamline curvature, if that were also included). Similarly, $\mathsf{F}^2/(2 + \mathsf{F}^2)$ is the kinetic-energy fraction, the fraction of the total specific energy associated with the velocity head. The relative size of the depth-energy fraction and kinetic-energy fraction and the characteristics of the screen surface determine whether the opening behaves primarily as an orifice (discharge proportional to $D^{1/2}$) or a series of shearing offsets (discharge proportional to V).

The value of C_{F} indicates the screening capacity of a slot opening as a function of the Froude number, while $C_{\mathsf{F}} \times p$ is an indicator of the performance of the entire screen surface, accounting for differences in screen porosity $p = s/(s + w)$. Fig. 6 shows the variation of C_{F} [Fig. 6(a)] and $C_{\mathsf{F}} \times p$ [Fig. 6(b)] as a function of the Froude number and compares the C_{F} and $C_{\mathsf{F}} \times p$ versus F relations for several hypothetical screens, demonstrating the effects of changing the wire tilt angle, slot width, and wire width. Values of C_{F} are nearly independent of changes in screen geometry at low Froude numbers, where orifice flow dominates. At high Froude numbers, C_{F} increases with increasing wire tilt, decreasing slot width, and increasing wire width. At high Froude numbers, the value of $C_{\mathsf{F}} \times p$ is directly proportional to the wire tilt angle, and nearly independent of the wire width and slot width, since changes in the value of C_{F} as a function of these parameters are offset by the changing porosity. At low Froude numbers, orifice-type flow dominates and $C_{\mathsf{F}} \times p$ is insensitive to the tilt angle, but directly proportional to the porosity.

It should also be noted that for $\mathsf{F} > 1$, the curves shown in Fig. 6 could be approximated by a power curve function, similar to the formulation proposed by Babb and Schlenker (1999) for discharge coefficients of perforated plate screens supporting supercritical flows. This suggests that similar flow mechanics may govern the screening of supercritical flows through tilted-wire screens and perforated plate screens. The

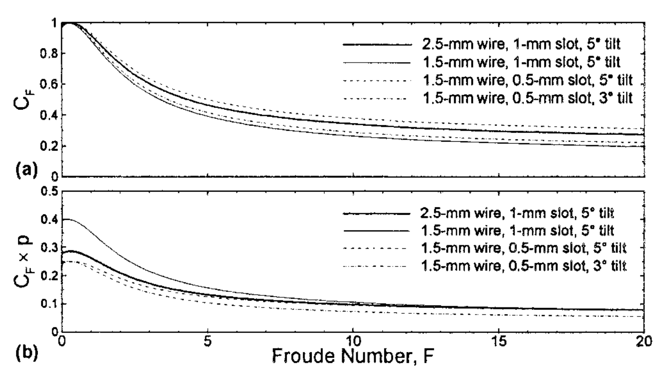


FIG. 6. Variation of C_{F} and $C_{\mathsf{F}} \times p$ versus Froude Number

formulation proposed here has the advantage that for $\mathsf{F} < 1$, C_F reaches a maximum value and then decreases slightly approaching $\mathsf{F} = 0$, while a power curve relation would predict an infinite discharge coefficient at $\mathsf{F} = 0$.

Values of C_{cv}

To determine values of C_{cv}, a test facility (Fig. 7) was constructed in which the flow through small samples of three different screens could be measured over a range of Froude numbers from about 2.5 to 16. The testing was performed in the Bureau of Reclamation's Water Resources Research Laboratory in Denver. The tested screens were 7.5–10 cm square or rectangular samples provided by screen manufacturers. Relevant screen dimensions are summarized in Table 1.

Dimensions and related uncertainties for the wire widths and slot widths of each screen were determined by measurement at 20 to 30 locations on each screen with a micrometer. Wire tilt angles were measured using two different techniques: (1) an optical comparator (screens 2 and 3); and (2) an optical reflection technique in which light from a laser pointer was reflected off the screen face so that the measured deflection of the beam could be used to compute the tilt of the wire (all screens). The measurements with the optical comparator were made by the National Institute of Standards and Technology, Gaithersburg, Md., and have an estimated expanded uncertainty of ±0.1° (95% confidence level). Measurements by the laser method were made at the Bureau of Reclamation and have an estimated uncertainty of ±0.25°. The optical comparator can only measure the tilt angle at the cut edges of the screen, while the laser method can be used at essentially any location on the screen. The reference line (zero tilt) for the measurements with the optical comparator was a line through the two high points of a screen over its full length (screens were slightly warped in some cases). For the laser method, the zero-reference was defined by laying a small mirror across the top of several wires at the location where the tilt was being measured and marking the location of the beam reflected by the mirror.

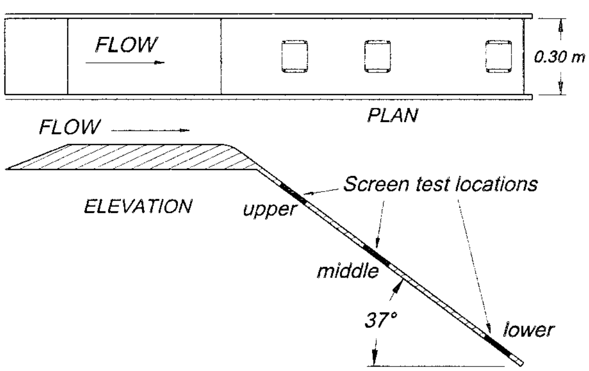


FIG. 7. Schematic Diagram of Screen-Test Facility Used to Determine C_{cv} Values

Columns 4, 6, and 8 in Table 1 provide the variabilities of the wire width, slot width, and tilt angle, and the uncertainties of the mean values used in subsequent calculations. The variability is the estimated point-to-point variation of the parameter over the screen surface, expressed at a 95% confidence level after factoring out the uncertainty associated with the measurement methods. Variability of the tilt angle for all screens was significantly greater than the uncertainty of either of the two methods used to measure wire tilt. The tilt angles determined using the laser-pointer method are shown in Table 1 and were used in all subsequent work described in this paper, primarily because this method could be applied to the entire screen surface, rather than just the cut edges of the screen. For comparison, the average tilt angles measured with the optical comparator on the edges of screens 2 and 3 were 3.38° and 5.71°, with wire-to-wire variabilities of 1.28° and 1.22°, respectively. For screen 2 the agreement between the two methods is excellent, while for screen 3 the difference in mean tilt angles is believed to be the result of measuring only at the cut edge of the screen with the optical comparator.

The test facility for determining values of C_{cv} consisted of a flume, 20 m long by 0.91 m wide, leading the flow to a 0.30 m-wide test section. Flow entered the test section over a short section of ogee-shaped crest leading to a sloped ramp inclined 37° from horizontal (Fig. 7). Screens were installed flush with the floor of the sloped flume at three locations. The upper location was approximately 20 cm (vertical) below the horizontal crest, and the lower location was about 81 cm below the horizontal crest. The third test location was added late in the test program about 45 cm below the horizontal crest. Crest lifts were also installed in increments of 1.9 cm each during later tests to produce flows with intermediate drop heights. Flows ranging from 0.023 to 0.46 $m^3/s/m$ could be delivered to the test section. Flow rates into the test facility were measured with the laboratory's fixed Venturi meters, which have a measurement uncertainty of <±0.5%.

Below the screen test location, a flow divider plate and collector box captured the flow passing through the screen and directed it to measurement locations. The position of the divider plate was varied slightly for each screen, but was generally about 2 to 3 cm from the leading edge of the screen. The divider plate allowed the flow through the first few screen slots to be measured separately from the flow through the downstream portion of the screen, with only the flow through the downstream portion of the screen used to compute values

TABLE 1. Screen Dimensions for Tests to Determine C_{cv}

		WIRE WIDTH w (mm)		SLOT WIDTH s (mm)		TILT ANGLE ϕ			
Screen number	Screen description	Mean	Variability Uncertainty of mean	Mean	Variability Uncertainty of mean	Mean (deg)	Variability Uncertainty of mean (deg)	Screen porosity $s/(s + w)$	Support rod spacing (mm)
1	2.38 mm (3/32 in.) wire, 1 mm slots, 7.7 cm × 9.2 cm	2.390	±0.015 ±0.003	1.021	±0.094 ±0.019	3.82	±0.63 ±0.08	0.299	70
2	1.52 mm (0.060 in.) wire, 1 mm slots, 10.4 cm × 7.2 cm	1.549	±0.010 ±0.001	0.993	±0.035 ±0.006	3.37	±1.39 ±0.14	0.390	19
3	1.52 mm (0.060 in.) wire, 0.5 mm slots, 7.4 cm × 8.7 cm	1.496	±0.015 ±0.003	0.467	±0.034 ±0.006	6.88	±0.99 ±0.13	0.238	14

of C_{cv}. Thus, the test section was representative of a section of a continuous screen panel. The flow through the first few screen slots was significantly lower than that through the downstream slots.

Flow through the section of the screen upstream from the divider plate was measured using a stopwatch and a 4-L graduated cylinder. Flow rates through the test portion of the screen, downstream from the divider plate, were measured using a half-90° V-notch weir.

The flow velocity above the screen face was measured at the downstream edge of the screen, using a 4.7 mm diameter pitot tube with a stagnation port diameter of 0.75 mm. Measurements were made about 6 mm above the screen face, except when shallow flow depths required lowering the pitot tube to keep it in the flow. It is recognized that the pitot tube is a less than ideal instrument for measuring velocity in supercritical flows due to the potential for flow separation from the leading edge of the tube and from the vertical stem. However, the pitot tube worked well for these tests and was much more practical (economically and operationally) than other alternatives, such as a noninvasive laser Doppler velocimeter. Flow profiles versus depth confirmed that this was an appropriate measurement technique, indicating that the velocity was essentially uniform immediately downstream from the screen, as one would expect due to the accelerating flow and continual removal of the boundary layer by the screen.

The velocity at the upstream edge of the screen was computed by applying the energy equation between the upstream and downstream edges of the screen. Velocity measurements made at the upstream and downstream edges of the screen during shakedown testing confirmed that this yields an accurate estimate of the upstream velocity. The velocity data and the measured discharges were used to compute flow depths and Froude numbers at the upstream and downstream ends of the test section, and average values were computed from the upstream and downstream values. The average values are plotted in the figures presented below.

During shakedown testing, screens were tested with various widths open to the flow and the excess width masked off by tape. These tests showed that the underlying support rods had no effect on the flow, i.e., the point of flow control was at or near the face of the screen. The position of the flow divider was also varied during shakedown testing to ensure that the test section was representative of a portion of a continuous screen.

Fig. 8 shows the values of $C_{\mathsf{F}} C_{cv}$ for the three tested screens as a function of the Froude number. Screens 2 and 3 were tested only at the upper ($\mathsf{F} = 2.5$–10) and lower ($\mathsf{F} = 7$–16) positions, while screen 1 was tested at all three positions and with variable crest heights. Velocities across the screens ranged from about 2.1 to 4.4 m/s (6.8 to 14.4 ft/s). Error bars indicate 95% uncertainty estimates propagated from uncertainties in the underlying measurements of discharge and velocity.

The form of the $C_{\mathsf{F}} C_{cv}$ versus F curves is similar to Fig. 6, which showed C_{F} versus F, but there are obviously significant differences in C_{cv} at the different test locations, as indicated by the distinct groupings of $C_{\mathsf{F}} C_{cv}$ values. For screens 2 and 3 there are two separate curves that do not coincide in the range of overlapping Froude numbers (about $\mathsf{F} = 7$ to $\mathsf{F} = 10$) that could be obtained at the upper and lower test positions. There are also separate curves for screen 1, although the differences are less distinct because tests were conducted at all three positions and with variable drop heights. Recalling that C_{F} is solely a function of the Froude number for any specific screen, the differences in the values of $C_{\mathsf{F}} C_{cv}$ at a given Froude number must be due to differences in the C_{cv} values at the different velocities produced by changing the drop height to the screen. These differences can be related to dimensionless parameters of the flow.

The computed values of C_{cv} were found to vary as a function of several dimensionless parameters, including the Reynolds number R, the Weber number W, the Froude number F, and the ratio R/W, which indicates the relative influence of viscous and surface tension forces and for a given fluid is a function solely of the velocity. The Reynolds number was computed using the tangential velocity (i.e., the velocity measured by the pitot tube), and the slot width of the screen, $\mathsf{R} = Vs/\nu$. The Weber number is $\rho V^2 s/\sigma$, where ρ is the fluid density and σ is the surface tension constant ($\sim$0.073 N/m). Several regression relations involving these parameters were explored, and the best relation for predicting C_{cv} was

$$C_{cv} = 0.210 + 0.0109(\mathsf{R}/\mathsf{W}) + 0.00803(\mathsf{F}) \tag{11}$$

The prediction performance of this relation is shown in Fig. 9. Horizontal error bars indicate uncertainty estimates for the measured C_{cv} values. Vertical error bars indicate uncertainty in the predicted C_{cv} values caused by underlying uncertainty in the values of F, R, and W.

IMPLEMENTING NUMERICAL MODEL

The model for screen structure performance summarized in Eqs. (3), (7), (8), (9), and (11) was implemented in a computer program. The model predicts the flow rate through the screen and the overflow off the toe of the screen, and provides detailed information on the flow depths and velocities along the length of the screen. The model uses unit discharge quantities.

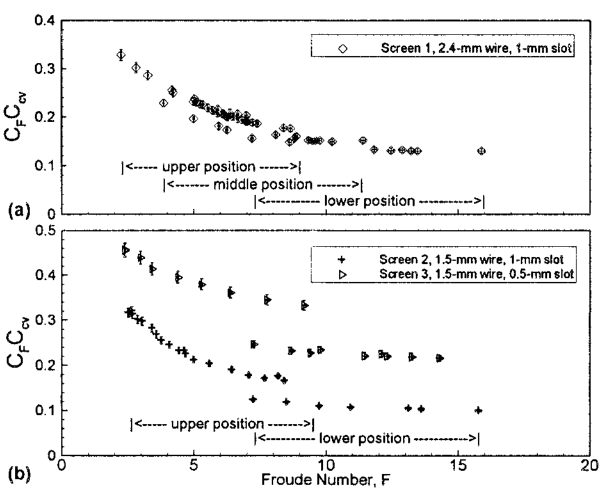


FIG. 8. Variation of $C_{\mathsf{F}} C_{cv}$ versus Froude Number for: (a) Screen 1; (b) Screens 2 and 3

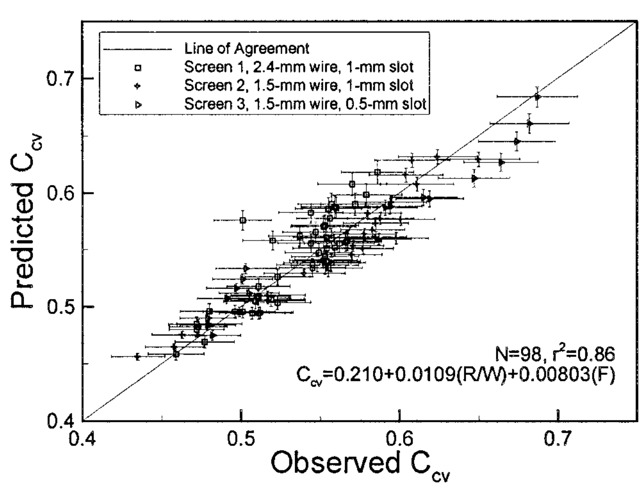


FIG. 9. Comparison of Observed Values of C_{cv} with Those Predicted Using Regression Eq. (11)

Computation of the flow profile begins with the assumption of potential flow over the crest and acceleration plate. The energy equation is used to determine the flow depth and velocity at the downstream edge of the acceleration plate, where the velocity profile is assumed to be uniform with depth, due to the inherent thinning of the boundary layer in an accelerating flow. Measurements of velocity profiles with the pitot tube verified this assumption.

Computations proceed wire-by-wire down the face of the screen, with the model determining the increment of flow diverted through the screen surface at each slot and the depth and velocity of the flow remaining above the screen. Calculations continue until all flow passes through the screen, or until the end of the screen is reached.

Effects of Friction on Flow Profile

The continuous removal of the bottom layer of the flow through the screen suggests that the development of a typical open-channel flow profile will not occur, and the effect of friction on the flow profile might be reduced or absent. To test this hypothesis, velocity profiles were measured with the pitot tube described earlier on one specific screen structure (configuration A-45 in Table 2) operating at a unit inflow of 0.117 $m^3/s/m$ (1.26 $ft^3/s/ft$). The measured profile is compared in Fig. 10 to velocity profiles computed with and without friction, using the Manning equation to compute S_f. An arbitrary roughness coefficient of $n = 0.012$ was selected for the profile computed with friction. With friction included, the velocity goes to zero at the end of the wetted section. The measured velocity profile and the profile computed without frictional effects do not exhibit this characteristic, and are substantially in agreement. Thus, friction can be neglected when computing the flow profile with (3).

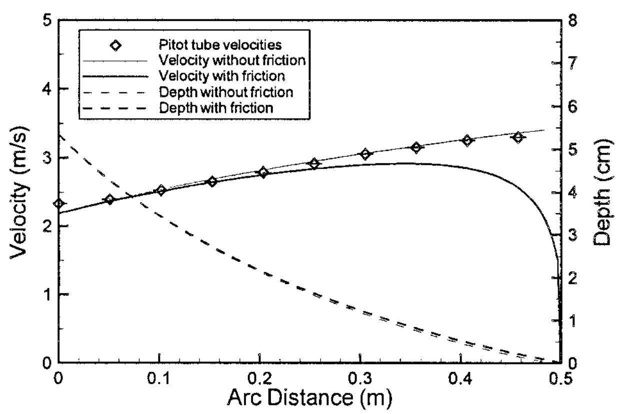


FIG. 10. Comparison of Measured and Computed Velocity Profiles

COMPARING NUMERICAL MODEL TO EXPERIMENTAL DATA

Several Coanda-effect screen structures have been tested in recent years by the Bureau of Reclamation (Wahl 1995, 2000), and the data collected offer a means for testing the performance of the numerical model developed here. Details of the tested screen structure dimensions and screen material properties are given in Tables 2 and 3, respectively. Table 4 shows the results of each test. Most screens were tested over a range of discharges up to a 50% bypass flow condition. All tests were conducted with clean screens and clear water, and in these prototype-size structures there was no air entrainment in the flow over the screens. For structures with greater drop heights than those tested, air entrainment might occur near the toe of the screen, and this would significantly affect screen performance.

Fig. 11 compares the screen performance predicted by the model to the observed performance for 97 of the 103 tests listed in Table 4 (63 cases without bypass flow, 40 cases with bypass flow). In the remaining 6 cases, the numerical model predicted slight overflow where none occurred, or did not predict overflow where slight overflow did occur, thus preventing direct comparison of the results. The agreement between the model and the experimental data is good throughout the range

TABLE 2. Coanda-Effect Screen Structure Dimensions

Screen	Initial incline θ_0 (deg)	Arc radius r (m)	Test width (m)	Acceleration plate configuration	Drop height (crest to top of screen) H_a (m)	Structure designation (Table 4)	θ_s (deg)	Arc length (m)
A (1 mm)	60	2.54	0.30	Ogee crest (design head 0.14 m)	0.37	A-60-1	25.0	1.12
						A-60-2	13.8	0.61
						A-60-3	10.3	0.46
A (1 mm)	55	2.54	1.42	Ogee crest (design head 0.19 m)	0.24	A-55	10.3	0.46
A (1 mm)	50	2.54	0.30	Ogee crest (design head 0.29 m)	0.25	A-50-1	25.0	1.12
						A-50-2	10.3	0.46
A (1 mm)	45	2.54	0.61	Ogee crest (design head 0.23 m)	0.13	A-45	13.8	0.61
B (0.5 mm)	60	3.05	0.61	Circular arc (0.30 m radius)	0.24	B-60	11.5	0.61

TABLE 3. Coanda-Effect Screen Material Properties

Screen	Nominal dimensions	WIRE WIDTH w (mm) Mean	WIRE WIDTH w (mm) Variability: Uncertainty of mean	SLOT WIDTH s (mm) Mean	SLOT WIDTH s (mm) Variability: Uncertainty of mean	TILT ANGLE ϕ Mean (deg)	TILT ANGLE ϕ Variability: Uncertainty of mean (deg)	Screen porosity $s/(s + w)$	Support rod spacing (mm)
A	1.52 mm (0.060 in.) wire, 1 mm slots	1.516	±0.026 ±0.005	0.979	±0.060 ±0.011	6.81	±1.15 ±0.14	0.391	19
B	1.52 mm (0.060 in.) wire, 0.5 mm slots	1.584	±0.026 ±0.005	0.535	±0.112 ±0.020	4.90	±1.25 ±0.24	0.252	37

TABLE 4. Data Collected From Laboratory Tests of Coanda-Effect Screen Structures

Structure (Table 2)	q_{inflow} ($m^3/s/m$)	Wetted flow distance (m)	q_{screen} ($m^3/s/m$)
A-60-1	0.035	0.17	—
A-60-1	0.040	0.18	—
A-60-1	0.044	0.19	—
A-60-1	0.048	0.22	—
A-60-1	0.052	0.24	—
A-60-1	0.056	0.25	—
A-60-1	0.064	0.25	—
A-60-1	0.071	0.31	—
A-60-1	0.077	0.31	—
A-60-1	0.085	0.34	—
A-60-1	0.095	0.37	—
A-60-1	0.102	0.41	—
A-60-1	0.108	0.41	—
A-60-1	0.112	0.42	—
A-60-1	0.117	0.43	—
A-60-1	0.120	0.44	—
A-60-1	0.121	0.44	—
A-60-1	0.150	0.51	—
A-60-1	0.171	0.56	—
A-60-1	0.191	0.61	—
A-60-1	0.220	0.69	—
A-60-1	0.224	0.66	—
A-60-1	0.260	0.79	—
A-60-2	0.178	—	0.176
A-60-2	0.180	—	0.174
A-60-2	0.185	—	0.178
A-60-2	0.190	—	0.181
A-60-2	0.204	—	0.185
A-60-2	0.215	—	0.190
A-60-2	0.216	—	0.192
A-60-2	0.230	—	0.196
A-60-2	0.242	—	0.196
A-60-3	0.122	—	0.114
A-60-3	0.125	—	0.119
A-60-3	0.129	—	0.121
A-60-3	0.135	—	0.123
A-60-3	0.148	—	0.128
A-60-3	0.167	—	0.133
A-60-3	0.183	—	0.138
A-60-3	0.216	—	0.145
A-55	0.018	0.10	—
A-55	0.038	0.23	—
A-55	0.061	0.31	—
A-55	0.080	0.38	—
A-50-1	0.038	0.22	—
A-50-1	0.048	0.25	—
A-50-1	0.059	0.29	—
A-50-1	0.073	0.33	—
A-50-1	0.093	0.41	—
A-50-1	0.116	0.48	—
A-50-1	0.141	0.56	—
A-50-1	0.163	0.61	—
A-50-1	0.176	0.64	—
A-50-1	0.188	0.66	—
A-50-1	0.209	0.74	—
A-50-1	0.241	0.79	—
A-50-1	0.261	0.86	—
A-50-1	0.284	0.91	—
A-50-1	0.301	0.97	—
A-50-1	0.328	1.02	—
A-50-1	0.340	1.07	—
A-50-1	0.373	—	0.359
A-50-1	0.389	—	0.366
A-50-2	0.107	—	0.106
A-50-2	0.156	—	0.130
A-50-2	0.166	—	0.134
A-50-2	0.220	—	0.151
A-45	0.024	0.15	—
A-45	0.039	0.20	—
A-45	0.059	0.28	—
A-45	0.060	0.28	—
A-45	0.070	0.32	—
A-45	0.085	0.36	—

TABLE 4. (*Continued*)

Structure (Table 2)	q_{inflow} ($m^3/s/m$)	Wetted flow distance (m)	q_{screen} ($m^3/s/m$)
A-45	0.098	0.41	—
A-45	0.110	0.43	—
A-45	0.135	0.51	—
A-45	0.164	—	0.162
A-45	0.168	—	0.162
A-45	0.184	—	0.173
A-45	0.189	—	0.171
A-45	0.190	—	0.172
A-45	0.192	—	0.175
A-45	0.192	—	0.177
A-45	0.196	—	0.175
A-45	0.197	—	0.176
A-45	0.202	—	0.169
A-45	0.206	—	0.177
A-45	0.216	—	0.185
A-45	0.249	—	0.194
B-60	0.025	0.14	—
B-60	0.038	0.21	—
B-60	0.046	0.24	—
B-60	0.050	0.25	—
B-60	0.064	0.32	—
B-60	0.072	0.36	—
B-60	0.077	0.38	—
B-60	0.086	0.41	—
B-60	0.105	0.47	—
B-60	0.129	0.58	—
B-60	0.141	—	0.131
B-60	0.158	—	0.136
B-60	0.174	—	0.142
B-60	0.182	—	0.145

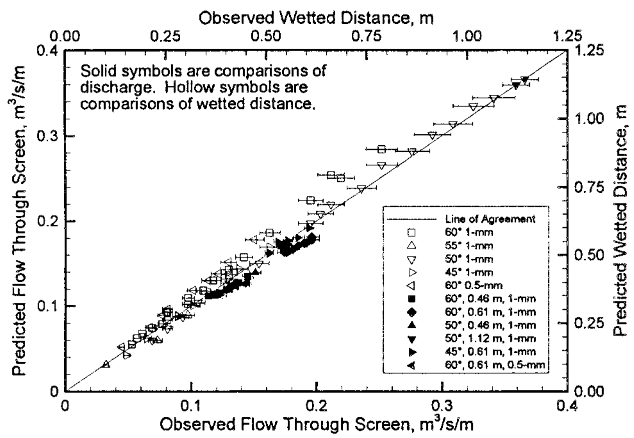


FIG. 11. Comparison of Laboratory Results and Predictions from Numerical Model

of flow conditions. It should be emphasized that this agreement was obtained without the need for further calibration of the model beyond the development of the regression relation for C_{cv} [(11)].

All of the test data shown in Fig. 11 were obtained from concave screens. The effects of screen curvature were accounted for in (4), and are significant. The predicted flow rates through the screens would be reduced by about 10% if the effects of screen curvature were neglected.

EXAMPLE APPLICATION

Capacities of screens with significant drop heights can be large. For example, the numerical model was applied to a hypothetical structure using a screen with a 1 mm slot width, 1.524 mm-wide wires, a 5° wire tilt angle, 3.05 m (10 ft) screen arc radius, and an initial screen inclination of $\theta_0 = 60°$. The drop height from the crest of the acceleration plate to the top edge of the screen was assumed to be 0.24 m (0.8 ft). The screen was assumed to span an arc of $\theta_s = 25°$, producing a total arc length of 1.33 m (4.36 ft). Similar designs are commercially available.

The capacity of this example screen is predicted to be 0.368 $m^3/s/m$ (3.96 $ft^3/s/ft$) at a zero-bypass flow condition, and 0.394 $m^3/s/m$ (4.25 $ft^3/s/ft$) at a 10% bypass rate. Changing the slot width to 0.5 mm and holding all other parameters constant changes the zero-bypass capacity to 0.313 $m^3/s/m$ (3.37 $ft^3/s/ft$) and the 10% bypass capacity to 0.322 $m^3/s/m$ (3.47 $ft^3/s/ft$)—reductions of 15 and 18%, respectively. These are relatively small changes compared to the 38% reduction in screen porosity corresponding to this change in slot width. This result is consistent with the earlier discussion of the variation of $C_F \times p$ and its insensitivity to changes in slot width and wire size.

The potential for high-flow capacity is an important consideration for screen designers. Overflow may be needed to carry debris downstream to a waste channel or to maintain a wetted screen surface and ensure safe downstream passage of fish. If capacity is underestimated, modification of the structure may be required, e.g., blocking a portion of the screen length. Additionally, knowledge of high-screen capacity may permit the use of a structure with a shorter crest length or lower drop height, which may yield economic savings or make a structure feasible at a site with limited available head or restricted construction space.

EFFECT OF VARYING DESIGN PARAMETERS

The numerical model presented in this paper can be used to examine the options available to designers when developing customized designs. Key parameters that designers might wish to vary include screen slot width and wire size, wire tilt angle, screen arc radius, screen inclination, drop height from top of crest to start of screen, and total drop height across the screen structure.

Screen Slot Width and Wire Size

The example given earlier showed that changing slot widths or wire sizes (and thus porosity) does affect flow capacity, but to a lesser degree than might be expected. The effects are most significant at high bypass ratios, which produce the lowest Froude numbers over the screen. In general, designers should make an initial selection of wire size and slot width with primary consideration for durability, constructability, and debris exclusion characteristics. Designs can then be fine-tuned if necessary to increase or decrease flow capacity.

Wire Tilt Angle

The wire tilt angle directly affects screen capacity because the offset height is proportional to the tilt angle [(1)]. A tilt angle of 5° has been used in most Coanda-effect screen installations to date. There may be disadvantages to increasing the tilt angle, such as increased debris retention caused by a higher offset height and a reduced ability to exclude small debris. As an upper limit, the tilt angle should always be less than the relief angle of the wire λ (Fig. 2). Typical relief angles are 10° to 15°, although wires with relief angles as small as 3° are available. There is also the possibility that tilt angles only slightly larger than the relief angle might allow the point of flow control to move from the top surface of the screen down into the slot opening, which would invalidate the model presented here. Screens with tilt angles approximately equal to or less than the relief angle were not tested in this study, so the exact upper limit on the tilt angle relative to the relief angle is unknown.

Screen Inclination, Drop Height, and Arc Radius

Changes in screen inclination, drop height to the start of the screen, and total drop height across the structure affect capacity primarily by increasing the specific energy in (9), and secondarily by changing the Froude, Reynolds, and Weber numbers, and thus the values of C_F and C_{cv}. Steeper screens exclude finer debris and smaller fish, but at the expense of more head drop for a given length of screen.

Concave screen panels have increased capacity due to the increased pressure on the screen face, and allow a longer length of screen for a given structural height and head drop. Use of a concave screen also flattens the discharge trajectory of the overflow jet whose energy must be dissipated downstream from the screen.

CONCLUSIONS

A theoretically based model for hydraulic performance of Coanda-effect screens has been presented, and a computer program to implement the model has been developed. The model predicts the depth and velocity profiles across a Coanda-effect screen using the equation for spatially varied flow with decreasing discharge. The flow over the screen surface is unaffected by hydraulic friction. In addition to the flow profile, the model predicts the total flow through the screen surface, the overflow off the toe of the screen, and the wetted length of screen when there is no overflow. The model includes a relation developed in this study to predict the flow through tilted-wire screening surfaces. The relation uses a modified orifice equation that incorporates the effects of the Froude number of the flow over the screen and the Reynolds and Weber numbers of the flow past the screen slot.

The model was used to predict the performance of several prototype-size Coanda-effect screen structures. Predicted and observed flow rates and wetted screen lengths compared favorably for nearly 100 tests spanning a range of hydraulic conditions. The model provides designers with a tool that can be used to accurately estimate screen capacity and develop economical screen structures for a variety of objectives and site conditions.

ACKNOWLEDGMENTS

The writer wishes to thank Robert Einhellig and Warren Frizell for their many valuable suggestions incorporated into the laboratory studies and the model presented here. Experimental data collection and model development were funded by the U.S. Bureau of Reclamation's Science and Technology Program (projects ER.99.29, ER.99.10, and NM022). Additional experimental data were collected in connection with a cooperative agreement with the Metro Wastewater Reclamation District, Denver. James Strong, Robert Weir, and John Brandt provided sample screens for testing, and Robert Weir suggested the optical reflection method used to measure wire tilt angles. The optical comparator measurements of wire tilt angles were made by Eric Stanfield and Shira Fishman of the National Institute of Standards and Technology, Gaithersburg, Md.

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NOTATION

The following symbols are used in this paper:

C_{cv} = combined contraction and velocity coefficient;
C_{F} = coefficient related to alignment of approach flow with screen opening; a function of Froude number;
D = flow depth;
E = specific energy;
F = Froude number;
g = acceleration of gravity;
H_a = drop height from crest of acceleration plate to top of screen;
H_s = head drop from upstream pool to top of screen;
n = Manning roughness coefficient;
p = screen porosity, $s/(s + w)$;
q = unit discharge;
q_{bypass} = unit discharge off toe of screen;
q_{inflow} = unit discharge at top of screen;
q_{screen} = unit discharge through screen surface;
R = Reynolds number;
r = screen arc radius;
S_f = friction slope;
s = open slot width between wires;
s' = length of slot opening from trailing edge of one wire to leading edge of next downstream wire, $\sqrt{s^2 + y_{\text{off}}^2}$;
V = velocity tangent to screen surface;
$\mathbf{V}_r$ = magnitude of resultant velocity vector approaching screen slot opening;
W = Weber number;
w = screen wire width;
y_{off} = offset height created by tilted wire;
α = energy coefficient;
ψ = angle between screen surface and line connecting leading edge of one wire to trailing edge of upstream wire;
Δq = unit discharge through screen slot;
δ = deflection angle of velocity vector approaching screen slot opening;
e = deflection angle from tail of one wire to leading edge of next downstream wire, relative to top surface of wire;
ϕ = wire tilt angle;
λ = wire relief angle;
ν = kinematic viscosity;
ρ = fluid density;
σ = surface tension force per unit length;
θ = angle of screen surface, measured from horizontal;
θ_s = included angle of screen arc; and
θ_0 = incline angle of screen from horizontal at top of screen.

Subscripts

1 = upstream end of control volume; and
2 = downstream end of control volume.

Appendix B

LA Regional Board Certification of Coanda Screens as a Full Capture Device, dated 11/15/2011, along with the technical report submittal package.

Matthew Rodriquez
Secretary for Environmental Protection

California Regional Water Quality Control Board
Los Angeles Region

320 W. 4th Street, Suite 200, Los Angeles, California 90013
(213) 576-6600 • FAX (213) 576-6640
http://www.waterboards.ca.gov/losangeles

Edmund G. Brown Jr
Governor

November 15, 2011

Gary Hildebrand, Assitant Deputy Director
Watershed Management Division
Department of Public Works, Country of Los Angeles
900 S. Fremont Ave.
Alhambra, CA 910803

CERTIFICATION OF THE COANDA SCREENS AS A FULL-CAPTURE DEVICE UNDER PART 7.1 TRASH TMDL OF THE LOS ANGELES COUNTY MUNICIPAL STORM WATER AND URBAN RUNOFF DISCHARGES PERMIT (Order No. 01-182, NPDES Permit No. CAS004001)

Dear Mr. Hildebrand:

We have reviewed your letter of September 22, 2011, and the accompanying report entitled, *Technical Report Coanda Screen Design Application for Full Capture TMDL Compliance, May 2011,* requesting certification for the Coanda Screens (by Coanda, Inc.) as full-capture device under Part 7.1 section B(1)(a)1 of the Trash Total Maximum Daily Load (TMDL) of the Los Angeles County Municipal Storm Water and Urban Runoff Discharges Permit (Order No. 01-182, as amended by Order No. R4-2009-0130).

Pursuant to Part 7.1, section B(1)(a)1 of Order No. 01-182, the undersigned hereby certify that Coanda Screens are deemed a full-capture device under the Trash TMDL.

Regional Water Quality Control Board, Los Angeles Region (Regional Board) staff review of the technical report and video show that the Coanda Screens satisfy the three criteria for a full–capture device:

1. Devices that traps all particles retained by a 5-mm mesh screens.

2. Design treatment capacity of not less than the peak flow resulting from a one-year, one-hour storm in the sub-drainage area, and

3. Essential technical information provided for adequate evaluation of the said full capture device.

In addition, Coanda Screens are comparable with previously certified full capture devices such as the connector pipe screens and vertical and horizontal capture screen inserts.

The Regional Board shall review and consider performance data on a continuing basis of all full-capture devices.

In the event that data demonstrate these devices are not performing to the full-capture standard set forth by the Trash TMDL, the Regional Board Executive Officer reserves the right and ability to rescind the certification for subsequent installations that are determined to be inadequate.

If you have any questions, please call Carlos D. Santos at (213) 620-2093.

Sincerely,

Samuel Unger

Samuel Unger, P.E.
Executive Officer

cc: Bruce Fujimoto, Division of Water Quality, State Water Board
Jennifer Fordyce, Office of Chief Counsel, State Water Board
Shahram Kharaghani, City of Los Angeles, WPD, Bu. of Sanitation

Technical Report
Coanda Screen Design
Application for Full Capture TMDL Compliance

Screen and Bypass Sizing Requirements

Prepared by
Steven E. Esmond, P.E.
Coanda, Inc.
for:

COUNTY OF LOS ANGELES
DEPARTMENT OF PUBLIC WORKS

May 2011

Contents

I. Purpose and Scope

The purpose of this report is to establish conservative design criteria for the Coanda Screen BMP in order to comply with the Los Angeles River and similar Trash Total Maximum Daily Load (TMDL) requirements for trash. The device must not only comply with the TMDL, but must also maintain the existing level of flood protection for Los Angeles County Flood Control District (LACFCD) facilities.

II. Abstract

Coanda screens are diagonally oriented, tilted wedgewire screens which can be installed inside of conventional curb entry storm water catch basins. Figure 1 shows the Coanda installation at the County of Los Angeles Department of Public Works test facility at the San Gabriel Dam in March 2011. Coanda screens can also be designed for small open channel applications. This technical report will address retrofit applications meant for curb inlet catch basins.

Figure 1 - Coanda Installation at LA County Test Facility

Coanda effect screens have been used for decades to screen small aquatic organisms and debris from water diversions. For more technical information on the theory and practical application of Coanda screens, refer to the U.S. Bureau of Reclamation web site.[1] Applications of Coanda screens designed specifically to remove debris from urban storm water have become increasingly popular across the United States, due in part to the screens' advantages. *"These screens have large flow capacities and are hydraulically self-cleaning without moving parts, so they require minimal maintenance."*[2]

III. Coanda BMP Description

The Coanda curb inlet BMP is designed entirely of 304 stainless steel, a material which provides superior corrosion resistance and high strength. The tilted wedgewire Coanda screen is designed to divert all runoff that enters the catch basin in a downward, vertical direction upon making contact with the Coanda screen. The Coanda screen is typically mounted immediately inside the catch basin at a diagonal orientation of 35 to 55 degrees from horizontal. The Coanda screen shown in Figure 1 is marked with directional arrows. Note that a narrow section

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[1] US Bureau of Reclamation, http://www.usbr.gov/pmts/hydraulics_lab/twahl/coanda/.

[2] Wahl, Tony L., "Design Guidance for Coanda-Effect Screens," US Department of the Interior, Bureau of Reclamation, Technical Service Center, Water Resources Research Laboratory, Denver, Colorado, Report No. R-03-03, July 2003,http://www.usbr.gov/pmts/hydraulics_lab/pubs/R/R-2003-03.pdf

of Coanda screen in Figure 1 was temporarily removed for the purpose of the photograph in order to expose the area underneath the screen, which is the pathway for filtered water to exit the catch basin after proceeding through the screen. Clear spaces between adjacent wedgewires typically fall within the range of 0.5 mm to 2.0 mm, in which no debris of that size or larger would be able to continue with the flow. As all storm runoff is diverted through the Coanda screen, debris is left behind to slide down the face of the screen into a debris compartment in the lower left quadrant of the catch basin. Hence, debris and storm runoff are instantaneously and permanently separated at the face of the Coanda screen. This concept is further illustrated on Figure 2, and can be viewed by video.[3]

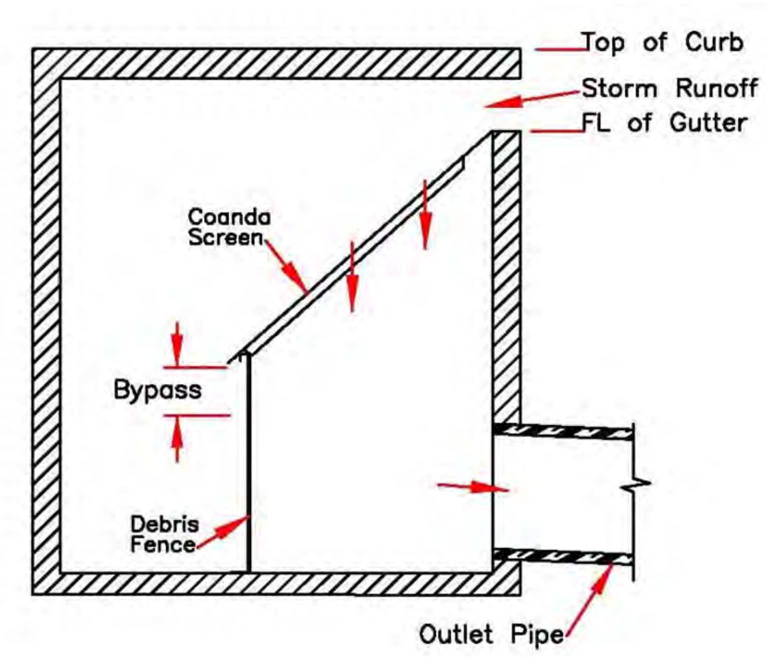

Figure 2 – Typical Coanda Curb Inlet Cross Section

The Coanda screen itself can be designed to treat the flow associated with any trash TMDL. In a properly sized Coanda catch basin BMP, all incoming storm water will flow through the Coanda screen. Only minor drippage associated with debris should make it to the debris compartment. Separated debris is not stored in a wet sump and is essentially stored dry.

For example, debris will slide down the face of the Coanda screen into the debris compartment in the lower left-hand quadrant of the catch basin in Figure 2 and will remain there until it can be removed by maintenance crews. The separation device beneath the Coanda screen but between the debris compartment and the pathway of treated storm water is called a debris fence. This debris fence, also made of 304 stainless steel, is a perforated plate material with numerous holes arranged in a tight pattern. Each hole is typically 4 mm to 5 mm in diameter. Thus, there is no opening anywhere in the catch basin larger than 5 mm. The net open area of the debris fence perforated plate material is approximately 50 percent.

LACFCD requires all catch basin BMPs to have some type of emergency bypass during peak flows in the event of blockage of a primary screen or filter caused by entrained debris. LACFCD also requires that the minimum size of an individual bypass opening be no smaller than 6 inches by 6 inches. Therefore, in each Coanda catch basin BMP a bypass section is provided along the top of the debris fence. The bypass section consists of a series of 6 inch square openings arranged in sequence at the top of the debris fence, lined up in a row, each opening spaced about 6 inches apart. The necessary number of openings of this size is dictated by the hydraulic requirements of the bypass flow rate. A sufficient number of openings will be provided

[3] http://www.coanda.com/video2.htm

to hydraulically pass the full incoming peak or maximum flow. The bypass openings can be seen in the photograph on Figure 1.

IV. Hydraulic Design Criteria

The Regional Water Quality Control Board (RWQCB) definition of a full capture system is as follows:

> *A full capture system is any single device or series of devices that traps all particles retained by a 5 mm mesh screen and has a design treatment capacity of not less than the peak flow rate Q resulting from a one-year, one-hour, storm in the subdrainage area.*[4]

Coanda screens employed in storm water applications typically have openings of 0.5 mm to 2.0 mm, the most common size being 0.5 mm and the largest being 2.0 mm. The Coanda Effect does not come into play when screen openings exceed 2.0 mm. Therefore, Coanda screens will always meet RWQCB particle size requirements.

Coanda screen installations must also satisfy the Los Angeles Department of Public Works hydrologic design criteria. Since the majority of LACFCD facilities are designed for a 10-year design storm frequency (Q_{10}),[5] the catch basin BMP must, at a minimum, be designed to handle the 10-year storm frequency. This ensures that flood protection will be maintained at current levels for all of Los Angeles County Flood Control District facilities.

The basis of design for any catch basin BMP is ultimately derived from the hydraulic capacity of the catch basin itself. The applicable hydraulic capacity can be determined from Chart D-10D of the LACFCD Hydraulic Manual.[6] The LACFCD states, *Curb opening catch basins are not installed on slopes larger than 0.04, so a slope of 0.04 can be assumed to be the maximum slope.*[7] Since steeper slopes yield higher flow capacities, the maximum flow for any catch basin should not exceed that which is based on a street slope of 0.04 percent. Using the data on LACFCD Chart D-10D, and applying a street slope of 0.04, the following equation was derived to describe the relationship between maximum flow Q and catch basin width:

Equation 1: $Q = 70\ (1\text{-}exp^{-0.02xCB})$, cfs

where CB = catch basin width, ft.

There may be instances in which the designer could use a flatter street slope when it is known, or an approved flow rate other than the maximum capacity of the catch basin. The following equations are extracted from the LACFCD methodology to be used to compute Q_{10} and $Q_{1\text{-}1}$:

Equation 2: $Q_{10} = 0.75\ Q$

[4] LARWQCB, http://www.waterboards.ca.gov/losangeles/water_issues/programs/tmdl/full_capture_certification.shtml
[5] LA County Department of Public Works Submittal for Full Capture Screens, April 2007, http://www.waterboards.ca.gov/losangeles/water_issues/programs/tmdl/fcc/la%20county%20full%20capture%20request%20package.pdf.
[6] "Hydrology Manual," Los Angeles county Department of Public Works, January 2006, http://www.ladpw.org/wrd/publication/.
[7] LACFCD Submittal to LARWQCB, April 2007, p. 6.

Equation 3: $Q_{1-1} = 0.22\ Q_{10}$

Once the proper design flow rates have been established, whether Q, Q_{10}, or Q_{1-1}, the designer is ready to proceed with the design of the Coanda catch basin BMP.

V. Catch Basin BMP Design

Figure 3 depicts the catch basin in elevation, featuring the critical dimensional components. The first step is to calculate the Coanda screen length, L_c, which is determined from the hydraulic design one-year, one-hour flow rate Q_{1-1}. For urban storm water applications involving screen openings of 0.5 mm, with the Coanda screen mounted at an angle that generally ranges from 35 to 55 degrees, a very conservative hydraulic loading is 250 gpm per sq.ft. Substantially higher loadings can be derived using USBR design criteria, this loading set intentionally low enough to allow for the interference of debris and long term wear and tear over a 50 year life cycle.

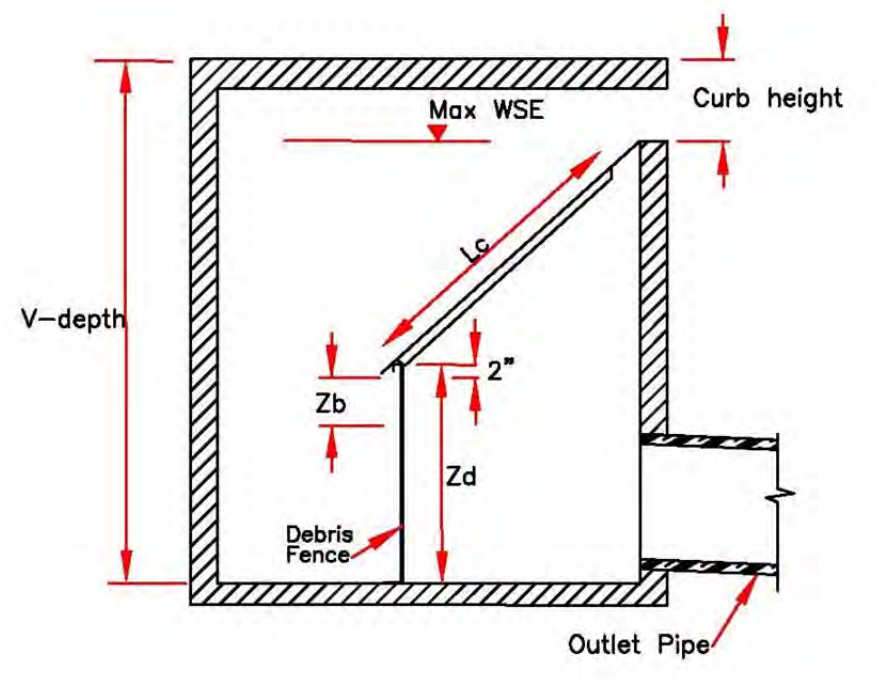

Figure 3 – Coanda BMP Dimensional Variables

Calculate L_c

The length of the Coanda screen L_c can be calculated by the following equation:

Equation 4: $$\mathrm{Lc} = \frac{Q}{250\ CB}\text{, feet}$$

where Q is the Q_{1-1} in gallons per minute, CB is catch basin width in feet.

Next, the designer will establish the angle of the screen. The range as stated above should be between 35 to 55 degrees with respect to horizontal. Contributing to this decision will in part be the depth (V-depth) and width of the catch basin.

Each Coanda screen comes with a stainless steel approach plate welded along the top which is securely anchored to the catch basin using stainless steel anchor bolts, and a stainless steel toe plate welded along the bottom which is securely anchored to the debris fence using stainless steel bolts. The top of the Coanda screen approach plate is located just inside the catch basin at or below the flow line of the gutter, therefore does not interfere with anything at or on the street. The Coanda screen will not interfere with street sweepers or with other types of screens if they happen to be installed in the gutter against the catch basin opening. Since these installations have no mechanical devices above the gutter elevation, there need not be any allowance for freeboard. Thus, the maximum depth of flow can be taken as the distance from the flowline of the gutter to the floor of the catch basin. In Figure 3, this distance is the V-depth minus the curb height, and the curb height is generally 8 inches in most cases.

Calculate Z_d

Next, the designer will determine the height of the debris fence Z_d shown in Figure 3. One may seek to maximize the height of the debris fence Z_d in order to maximize the volume of debris compartment. It is often the case that the designer will locate the debris fence along the midpoint or centerline of the catch basin. Thus, the value of Z_d is ultimately derived from the angle and length of the Coanda screen as well as of the geometry of the catch basin itself.

The hydraulic properties of the Coanda BMP are illustrated in Figure 4.

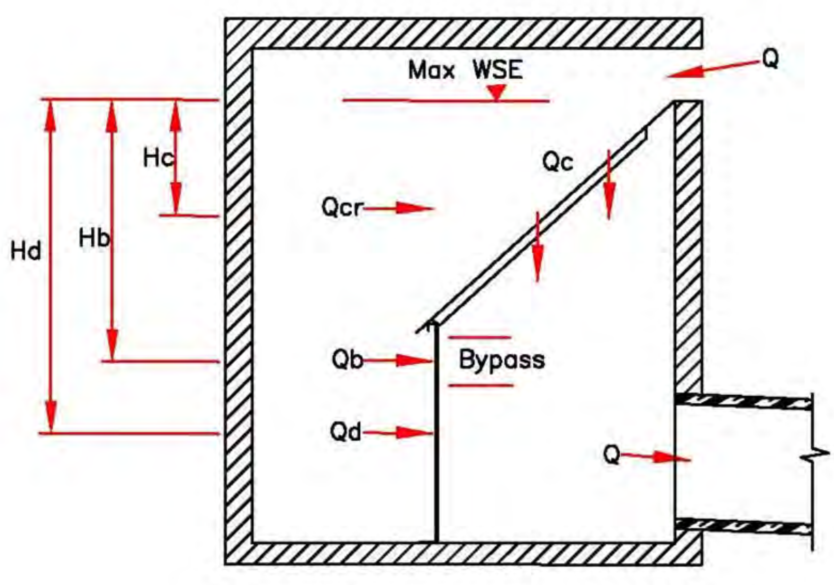

Figure 4 – Coanda BMP Hydraulics

The designer will determine the hydraulic capacity of the debris fence using the orifice equation:

Equation 5: $Q = C\,A\,\sqrt{2gH}$, cfs

For all calculations involving Equation 5, the value of g = 32.2 ft sec^{-2}. In keeping with LACFCD standard practice, the orifice coefficient C for the bypass is 0.60, and for the debris fence is 0.53.[8] The cross sectional area A is the area of the debris fence in square feet (less the area of the bypass A_b), multiplied by the ratio of the net clear opening, which for typical perforated plate debris fence material is 0.50. The value of the head H is equal to H_d (shown in Figure 4), being the distance in feet from the maximum water surface to the vertical centroid of the debris fence.

Using this information, the value of Q_d (flow rate through the debris fence) can be calculated. The calculated value of Q_d should be equal to or greater than the maximum flow Q. Should the calculation reveal a hydraulic deficiency, the designer should re-visit the geometry of the catch basin or change the Coanda screen angle in order to adjust the size of the debris fence accordingly.

Calculate Z_b

Next, the designer will determine the hydraulic capacity of the bypass section. Refer to Figure 3. Having determined the height of the debris fence Z_d, the top of the bypass openings will normally be set 2 inches below the top of the debris fence. The minimum bypass opening Z_b (having been set by regulation) is 6 inches. Typically, Z_b will be set at 6 inches unless a greater value is needed to handle the bypass flow.

The designer will again employ Equation 5, using a C-coefficient of 0.60 and H set at the value of H_b (shown in Figure 4), which is the distance from the maximum water surface to the centroid of the bypass openings. The total bypass opening area is determined by multiplying the total length of the bypass openings L_b times their vertical height Z_b. In most Coanda BMP installations, the bypass section will be a series of 6-inch by 6-inch slots located 2 inches below the top of the debris fence, each slot separated from the next slot by 6 inches of debris fence. Thus, the value of L_b can be approximated for any length of catch basin using the following equation:

Equation 6: $L_b = (CB – 1) \times 6$ (inches)

where CB = width of catch basin in feet.

The area of the bypass can be calculated as follows:

Equation 7: $A_b = L_b \times Z_b$

Using Equation 5, substituting A_b for A and H_b for H, the designer will calculate the bypass flow rate Q_b. If this calculation reveals the bypass has insufficient hydraulic capacity, then the designer will increase the values of L_b and/or Z_b accordingly, taking into account the practical implications on the geometry of the debris fence and its necessary function.

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[8] Ibid, p. 9.

Optional Calculation of Reverse Coanda Screen Flow Q_{cr}

As a final but optional check, the designer can evaluate what might happen if both the debris fence and the bypass were to become plugged, and if the water were to enter the catch basin without passing through the Coanda screen. This condition would be analogous to Q_{cr} (shown in Figure 4), where the flow would go in a reverse direction through the Coanda screen openings. In this situation, the Coanda screen would behave as a simple orifice. The designer could use Equation 5, taking A as the area of the Coanda screen times 0.30 (typically the net clear opening for most Coanda screens), H set at a value of H_c (Figure 4), corresponding to the distance from the maximum water elevation to the centroid of the Coanda screen, and a C-coefficient of 0.53. Such a condition is almost never seen in practice, but was intentionally created at the County of Los Angeles Department of Public Works test facility at the San Gabriel Dam on March 2, 2011. Both the debris fence and the bypass were intentionally covered and taped with plastic, forcing all flow to go through the Coanda screen either in the normal or reverse direction. Flow was increased to the maximum that could be delivered to the catch basin, causing some flow to shoot past the Coanda screen upon entry. The combination of Q_c and/or Q_{cr} were able to handle the total flow, as can be seen in the video.[9]

VI. Example Calculation

Assume that a standard Los Angeles County catch basin that is 10 feet wide and has a V-depth of 3.5 feet, is to be retrofitted with a Coanda BMP.

Flows

Using Equation 1: $Q = 70\ (1\text{-}\exp^{-0.02 \times CB})$, cfs

where CB = catch basin width = 10 ft, Q = 12.7 cfs.

Using Equation 2: $Q_{10} = 0.75\ Q = 9.5$ cfs

Using Equation 3: $Q_{1\text{-}1} = 0.22\ Q_{10} = 2.1$ cfs

Coanda Screen

Using Equation 4: $\mathrm{Lc} = \dfrac{Q}{250\ CB}$, feet

where Q is the $Q_{1\text{-}1}$ flow = 2.1 cfs or 945 gallons per minute, and CB is 10 feet. In the vast majority of applications, the width of the Coanda screen will be the same as the catch basin width CB, which in this example is 10 feet. Using Equation 4 above, L_c = 0.38 feet or 5 inches. At this point, the designer may choose to designate either a longer screen or add approach and toe plate to provide a practical working length of screen material. It is generally recommended that the debris fence would sit no closer than 12 inches from the interior wall of the catch basin, thus, when oriented on a 45 degree angle, the total length of screen plus approach and toe

[9] Video showing Coanda BMP undergoing testing at LACFCD San Gabriel Dam Test Facility, March 2, 2011, http://www.youtube.com/watch?v=8EB8OAI3T-g

plates would be $12 \, x \, \sqrt{2}$ = 17 inches. The Coanda screen could comprise as little as 5 inches of the 17, leaving a total of 12 inches for toe plate and approach plate.

Debris Fence

The next step is to determine the height of the debris fence. Assuming the Coanda screen is mounted on a 45 degree angle, using the V-depth of 42 inches, from simple geometry the height of the debris fence Z_d = 24 inches = 2.0 feet.

Next, calculate the bypass open area A_b. Use Equation 6 to calculate the required length of bypass openings L_b = (CB – 1) x 6 = 54 inches = 4.5 feet. Thus, according to Equation 7, using bypass height of 6 inches, the total bypass area A_b = L_b x Z_b = 4.5 x 0.50 = 2.25 sq.ft.

The net open area of the debris fence = (Z_d x CB – A_b) x 0.50 = (2.0 x 10 -2.25) x 0.50 = 8.87 sq.ft. The average hydraulic head on the debris fence is estimated to be 23 inches or 1.91 feet. Using Equation 5, with C = 0.53, A = 8.87, and H = 1.91, the resulting Q_d = 52.1 cfs. (The debris fence must have a hydraulic capacity of at least Q or 12.7 cfs, therefore, the debris fence is adequate to carry the maximum flow.)

Bypass

Having previously calculated the bypass area A_b to be 2.25 sq.ft., the hydraulic head acting upon the bypass open area is estimated to be 15 inches or 1.25 feet. Using Equation 5, with C = 0.60, A = 2.25, and H = 1.25, the resulting Q_b = 12.1 cfs. The bypass section must have a hydraulic capacity of at least Q or 12.7 cfs, therefore, the bypass openings need to be increased from a 6 inch width to 7 inches. Using Equation 6, the revised bypass opening would be: L_b = (CB – 1) x 7 = 63 inches = 5.25 feet. Changing the bypass width from 6 to 7 inches therefore increases the value of A_b from 2.25 sq.ft. to 2.63 sq.ft. Re-calculating the bypass hydraulic capacity using Equation 5, with C = 0.60, A = 2.63, and H = 1.25, the resulting Q_b = 14.1 cfs. The bypass section must have a hydraulic capacity of at least Q or 12.7 cfs, therefore, 7 inch wide x 6 inch high bypass openings will be more than adequate to carry the maximum flow.

Reverse Flow Through Coanda Screen

The net open area for the Coanda screen (A_{cr}) is its length times its width times the net clear opening, which is 0.30. Thus, A_{cr} = L_c x CB x 0.30 = 0.38 x 10 x 0.30 = 1.14 sq.ft. The hydraulic head acting upon the Coanda screen is estimated to be 6 inches or 0.50 feet. Using Equation 5, with C = 0.53, A = 1.14, and H = 0.50, the resulting Q_{cr} = 3.4 cfs. The Coanda screen in this example is designed to carry the $Q_{1\text{-}1}$ flow of 2.1 cfs. If the designer wishes to increase Q_{cr}, this can be accomplished by increasing the length of the Coanda screen L_c from 5 inches to as much as 17 inches in this example. Note that the BMP design does not depend on Q_{cr} at all, because the debris fence and the emergency overflow are each designed to carry the maximum flow Q.

VII. Value Added Benefits

This report has demonstrated that the Coanda screen BMP meets Trash TMDL design criteria. Most Coanda urban storm water BMPs are equipped with 0.5 mm screens, a few have 1.0 mm screens. Coanda removes much smaller particles than the Trash TMDL requirement of 5.0 mm. Debris is stored in an essentially dry state, eliminating the concern of nutrients leaching into a wet sump. In addition, the existing level of flood protection of the Los Angeles County Flood Control District facilities is not compromised in any way.

All materials of construction are stainless steel, structurally designed to withstand the maximum loadings to comply with the California Building Code. The life cycle of a typical Coanda BMP installation should be 40 to 50 years. As previously referenced, the US Bureau of Reclamation states that these screens have the ability to handle high flow capacities, they self-clean hydraulically without any moving parts, and have minimal maintenance requirements.

Coanda screens remove preproduction plastic pellets or nurdles greater in size than the screen spacing with 100 percent efficiency. These tiny plastic materials have become an environmental nuisance. They are often spherical or elliptical in shape, with a minimum size typically in the range of 2.5 to 4.0 mm in diameter. The Coanda BMP readily removes all nurdles, as can be seen on video.[10]

VIII. Maintenance Requirements

The Coanda curb inlet should be cleaned and debris removed on a periodic basis. Experience indicates that cleaning cycles may vary from one to three times per year, depending upon the acreage draining into the curb inlet, land use, and other characteristics of the watershed.

Captured debris should dry quickly and remain inert in the debris compartment. If there happen to be illicit discharges in dry weather runoff, cooling condensate water, or irrigation overflows, these could pose a nuisance and could keep captured debris moist in other types of trash BMPs. However, the Coanda curb inlet is designed so that low flow runoff should not make direct contact with captured debris. If this type of problem occurs and persists, contact the manufacturer.

Debris removal and cleaning can be carried out in most typical curb inlets within about 30 minutes using ordinary hand tools. The tools most helpful are:

1. Square-blade scoop
    a. Long handle for very large curb inlets
    b. Short handle for most other curb inlets
2. Straw broom
3. Metal dust pan

At least one alternative to manual cleaning would involve debris removal using a vacuum truck.

When carrying out a cleaning operation, observe the following guidelines:

1. Work in teams of two persons.
2. Do not enter the curb inlet unless a confined space entry program has been implemented, and then follow permit confined space program requirements.
3. Wear long sleeve shirt, full length pants, gloves and a hat.
4. When possible, in the interest of safety, park a vehicle along the curb with emergency flashing light in front of the curb inlet.

[10] http://www.coanda.com/video3.htm

5. Install traffic cones, yellow caution tape, and/or create barriers around the access cover to divert pedestrian movement around the access.
6. Remove the access cover.
7. Clean the curb inlet and place all debris in plastic bags.
8. Seal the plastic bags and immediately place on a truck for transport to disposal.
9. Should there be any debris on top of the Coanda screen, brush it off with a broom.
10. If animals are found in the curb inlet, notify animal control.
11. Note any unusual conditions and do not attempt to remove anything except ordinary debris.
12. If there has been any damage to the Coanda screen or debris fence, contact the manufacturer immediately.

Appendix C

Jungseok Ho, Joseph Prado, and Lizbeth Orduno, “Coanda-Effect Screen Velocity Monitoring Using particle image Velocimetry,” slides from a technical paper presented EWRI ASCE LID Conference, January 2015, Houston, TX. This presentation is the summary of a recent Ph.D. dissertation at the University of Texas on the subject of modeling flow through Coanda Screens.
.

Coanda-effect Screen Surface Velocity Monitoring using Particle Image Velocimetry

- EWRI ASCE LID Conference, January 2015, Houston, TX -

Jungseok Ho, Jose Prado, Lizbeth Orduno
University of Texas Pan-American, Civil Engineering, Edinburg, TX

Coanda Screen Application for LID

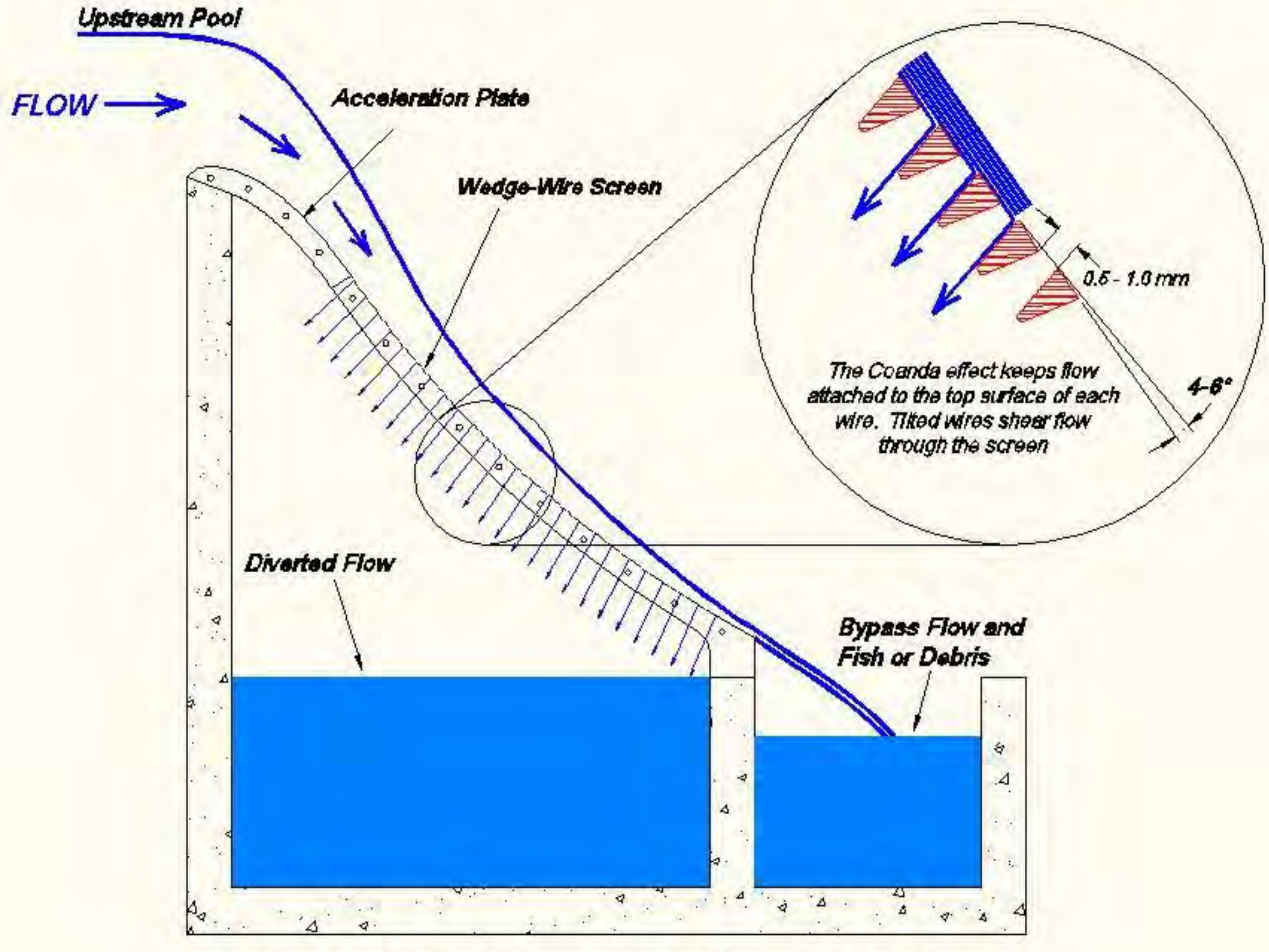
Coanda-effect screen application at storm water quality facility, www.coanda.com

Coanda-effect screen application at Storm water Quality Facility, Albuquerque, New Mexico. Ho and Daggett (2011) AWRA conference.

Coanda-effect screen LID applications   www.hydroscreen.com

Coanda-effect screen application in River intake fish by-pass, WRRL, USBR

Coanda-effect screen application in
River intake fish by-pass, WRRL, USBR

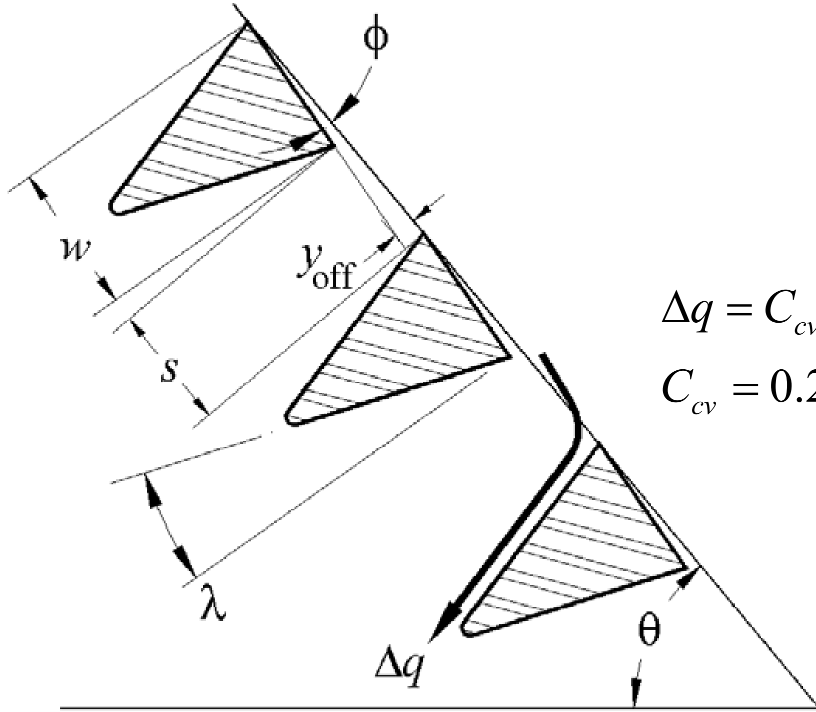


Features and Typical Arrangement of a Coanda-Effect Screen

Tony Wahl (2003), Design Guidance for Coanda-effect Screens, R-03-30, WRRL, USDI, Denver CO.

Outlines

1. Coanda-effect Screen
   - Hydraulics and theory
   - Study objectives and scope
2. Physical Model
   - Particle Image Velocimetry
   - Laboratory flume for coanda-effect screen
3. Modeling Results
   - PIV setup and filtration
   - Numerical model – CFD computations
   - Measure of model performance – PBIAS parameter
4. Summary



$$\Delta q = C_{cv} C_{Fr} s \sqrt{2gE}$$

$$C_{cv} = 0.21 + 0.0109\left(\mathrm{Re}/\,\mathrm{We}\right) + 0.00803\left(\mathrm{Fr}\right)$$

where,

Δq = discharge through the slot per unit width of screen structure

C_{cv} = a calibration coefficient to account for flow contraction and non-uniform velocity distribution

C_{Fr} = a coefficient to account the screen geometry and the Froude number

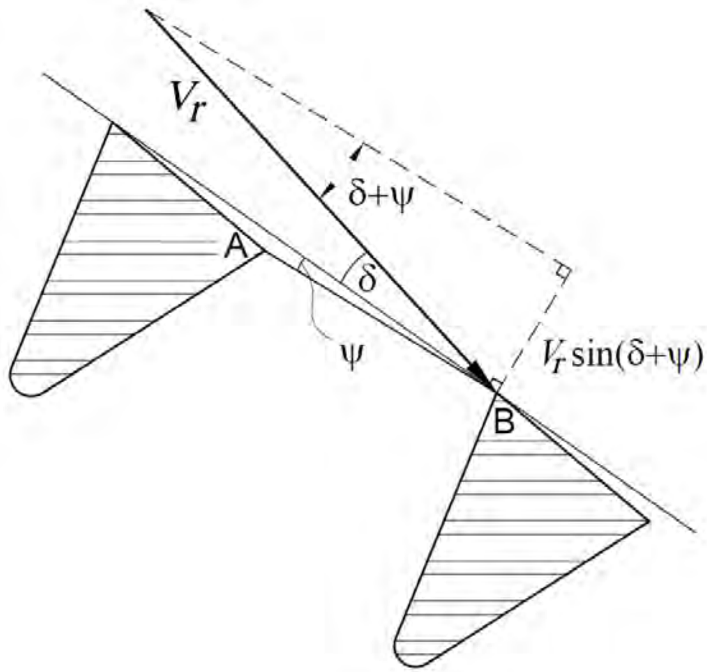
s = slot width

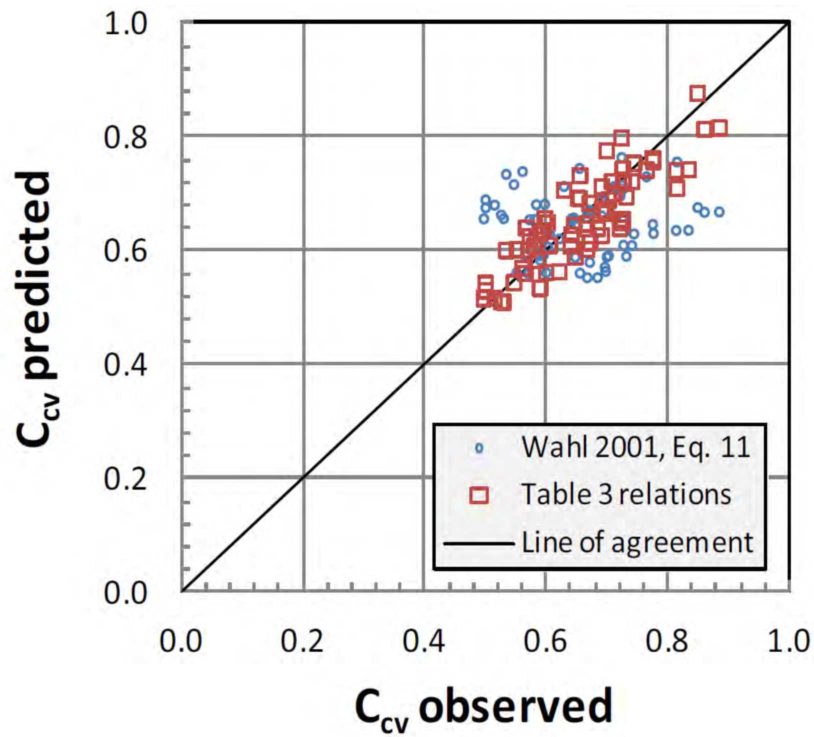
g = gravity acceleration

E = specific energy of the flow above the screen face

Re, We, and Fr = Reynold number, Weber number, and Froude number

Tony Wahl (2003), Design Guidance for Coanda-effect Screens, R-03-30, WRRL, USDI, Denver CO.



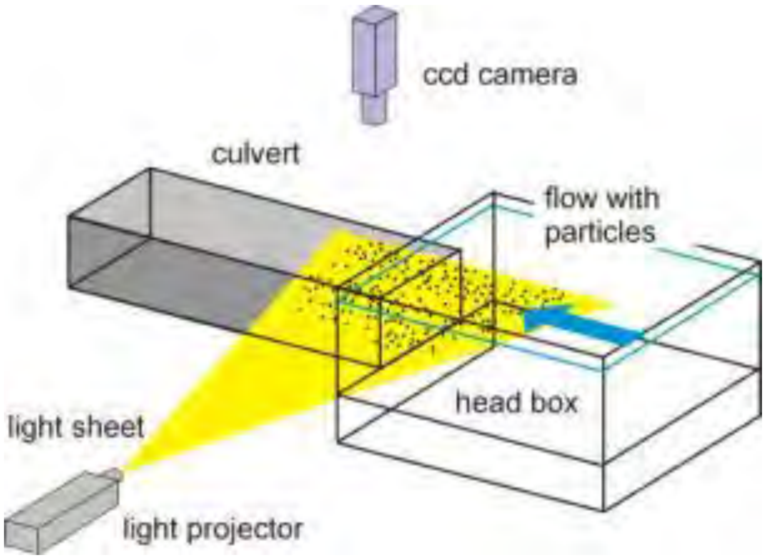


$$C_{cv} = 0.21 + 0.0109(\mathrm{Re}/\,\mathrm{We}) + 0.00803(\mathrm{Fr})$$

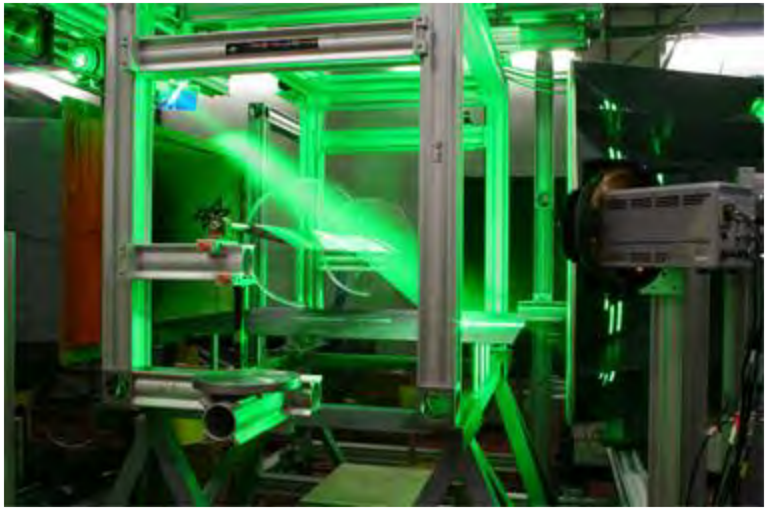
$$\mathrm{Re} = \frac{\rho V_r L}{\mu}, \quad \mathrm{We} = \frac{\rho V_r^{\,2} L}{\sigma}, \quad \mathrm{Fr} = \frac{V_r}{\sqrt{gL}}$$

Tony Wahl (2003), Design Guidance for Coanda-effect Screens, R-03-30, WRRL, USDI, Denver CO.

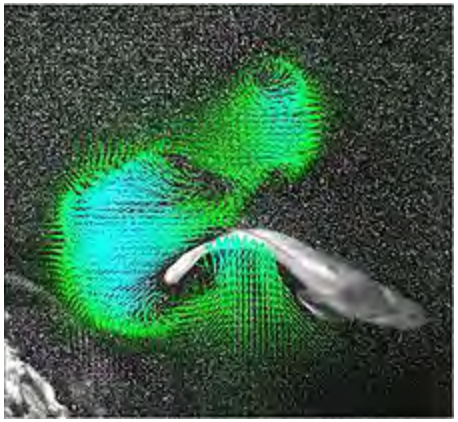
Particle Image Velocimetry



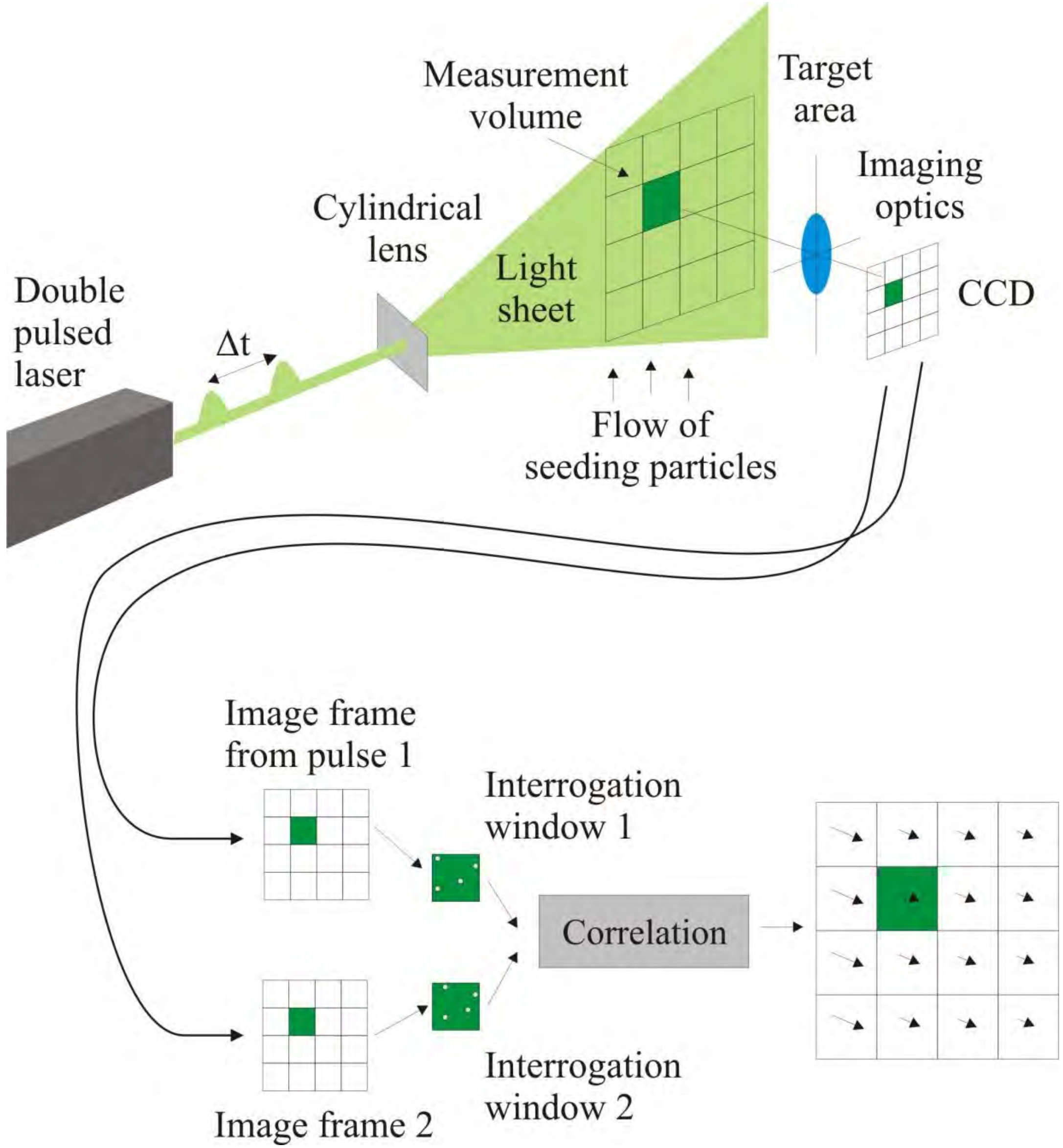
Federal Highway Administration, USDOT
(http://www.fhwa.dot.gov/research/)



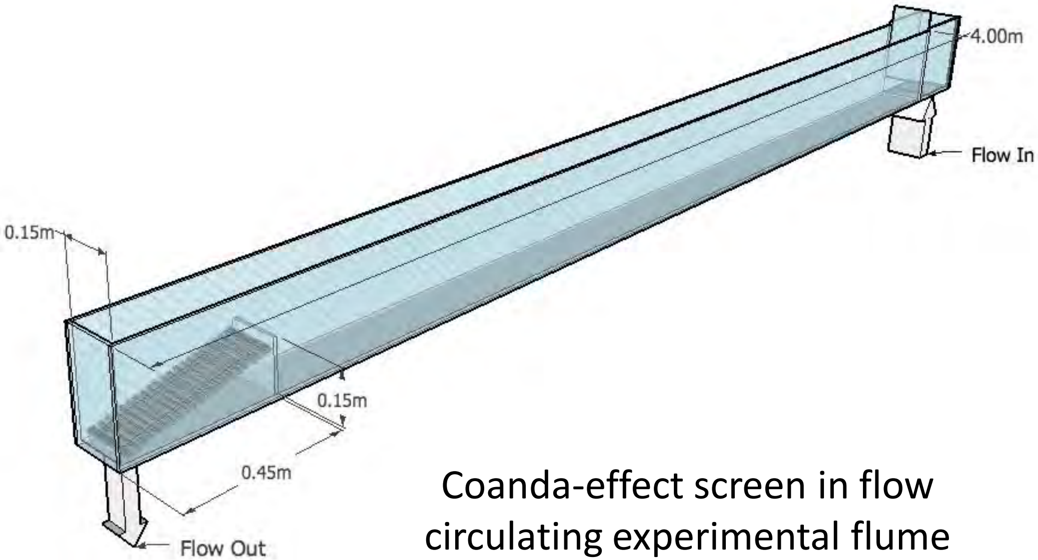
Airfoil in wind turner, DLR
(http://www.dlr.de/)



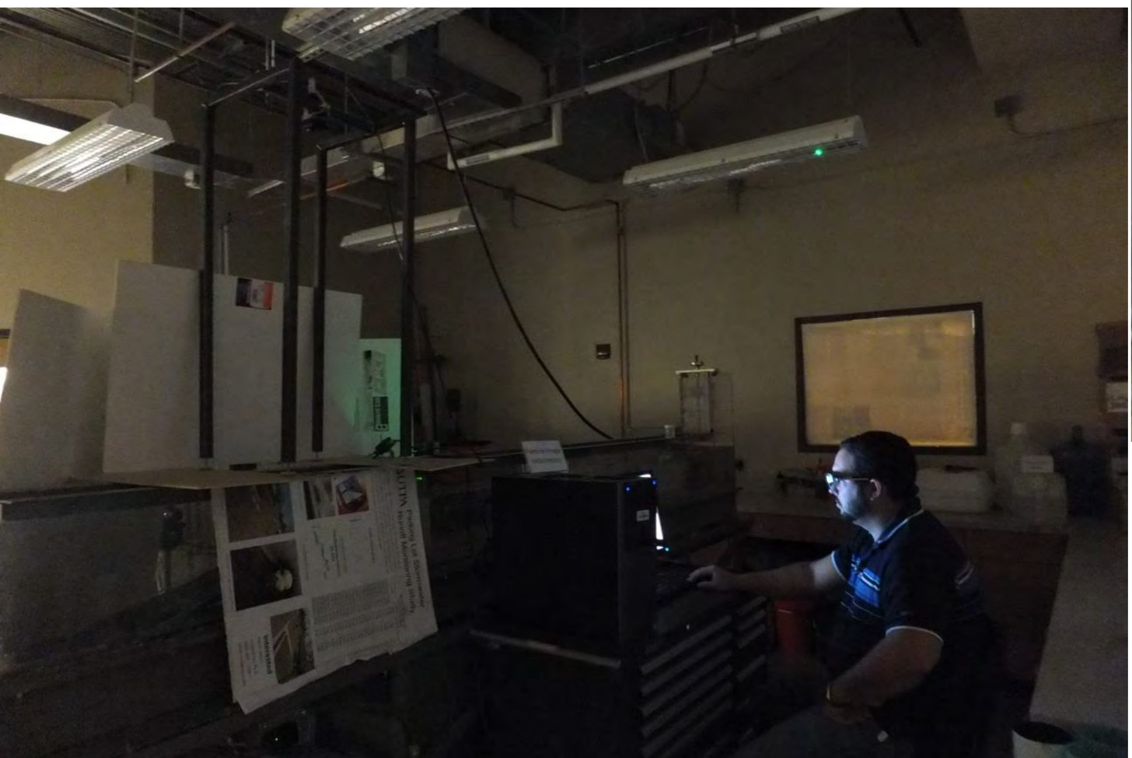
Tufts University
Dept. of Biology
(http://ase.tufts.edu)

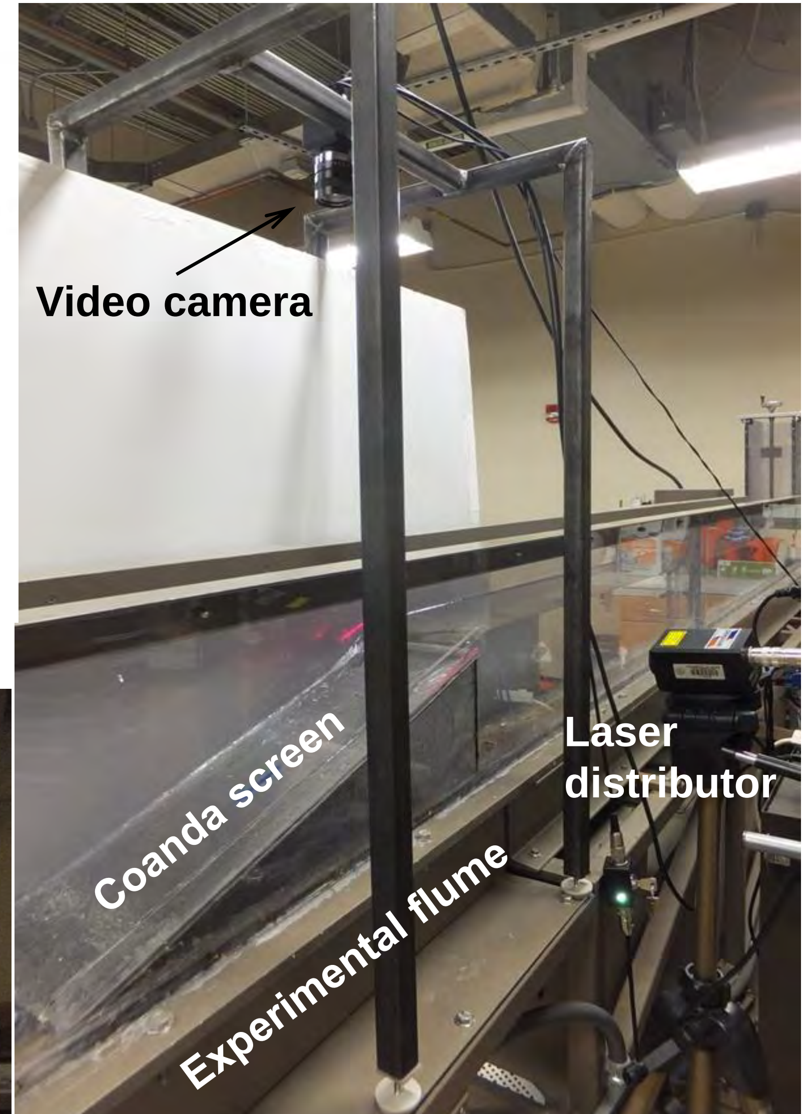


Technische Universitat Munchen
(http://wwwcg.in.tum.de/research)



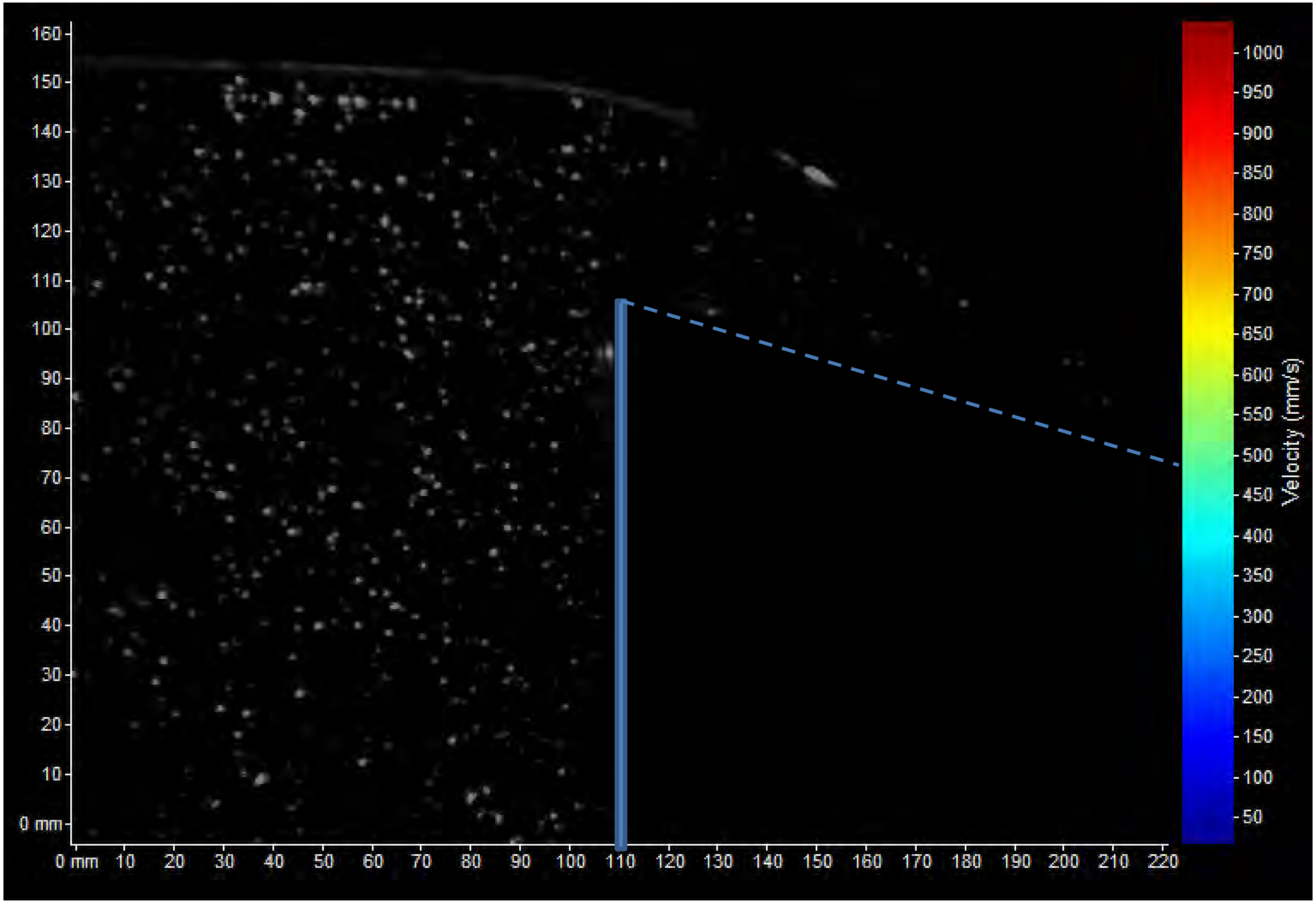
Coanda-effect screen in flow circulating experimental flume

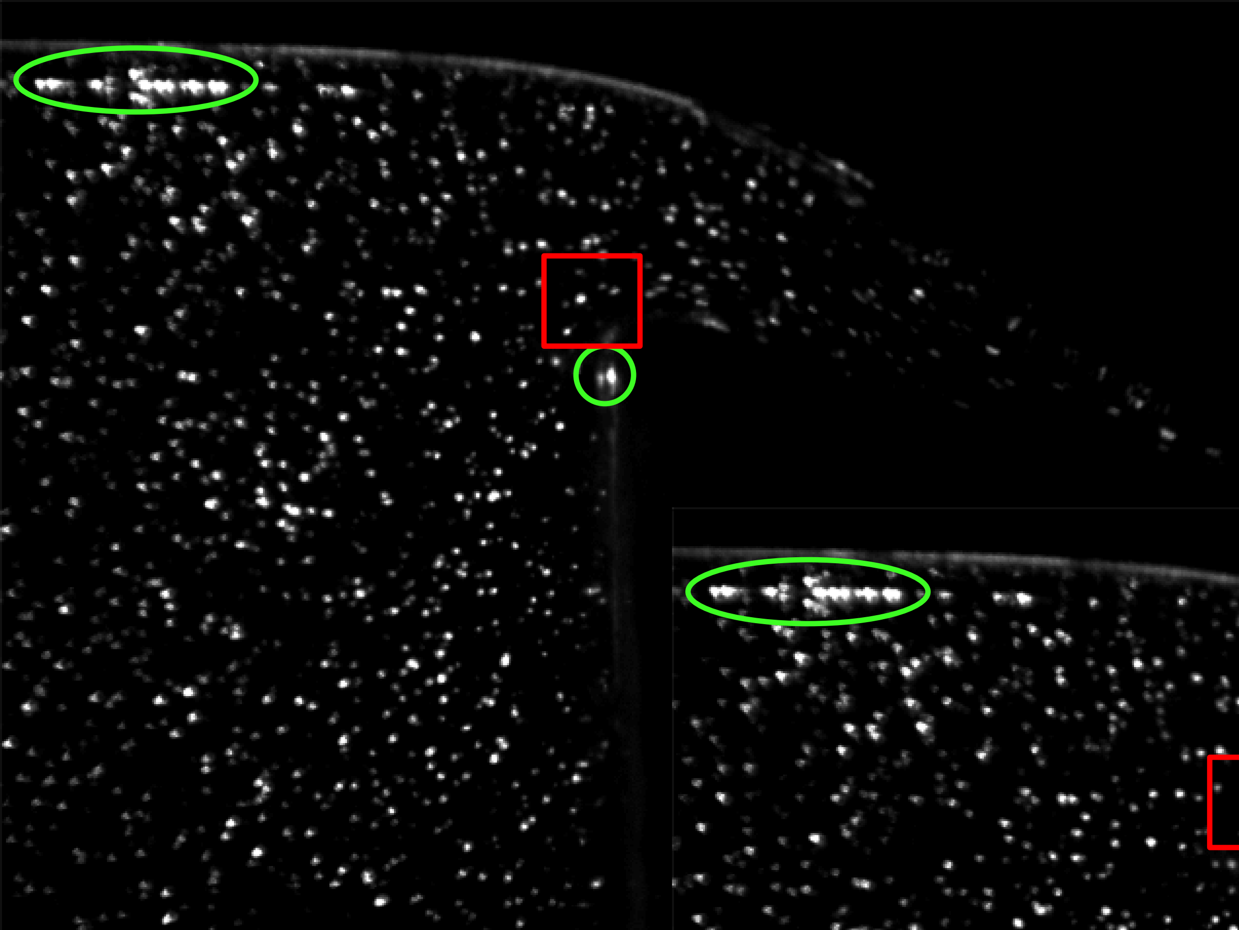




Flow transition over the coanda screen

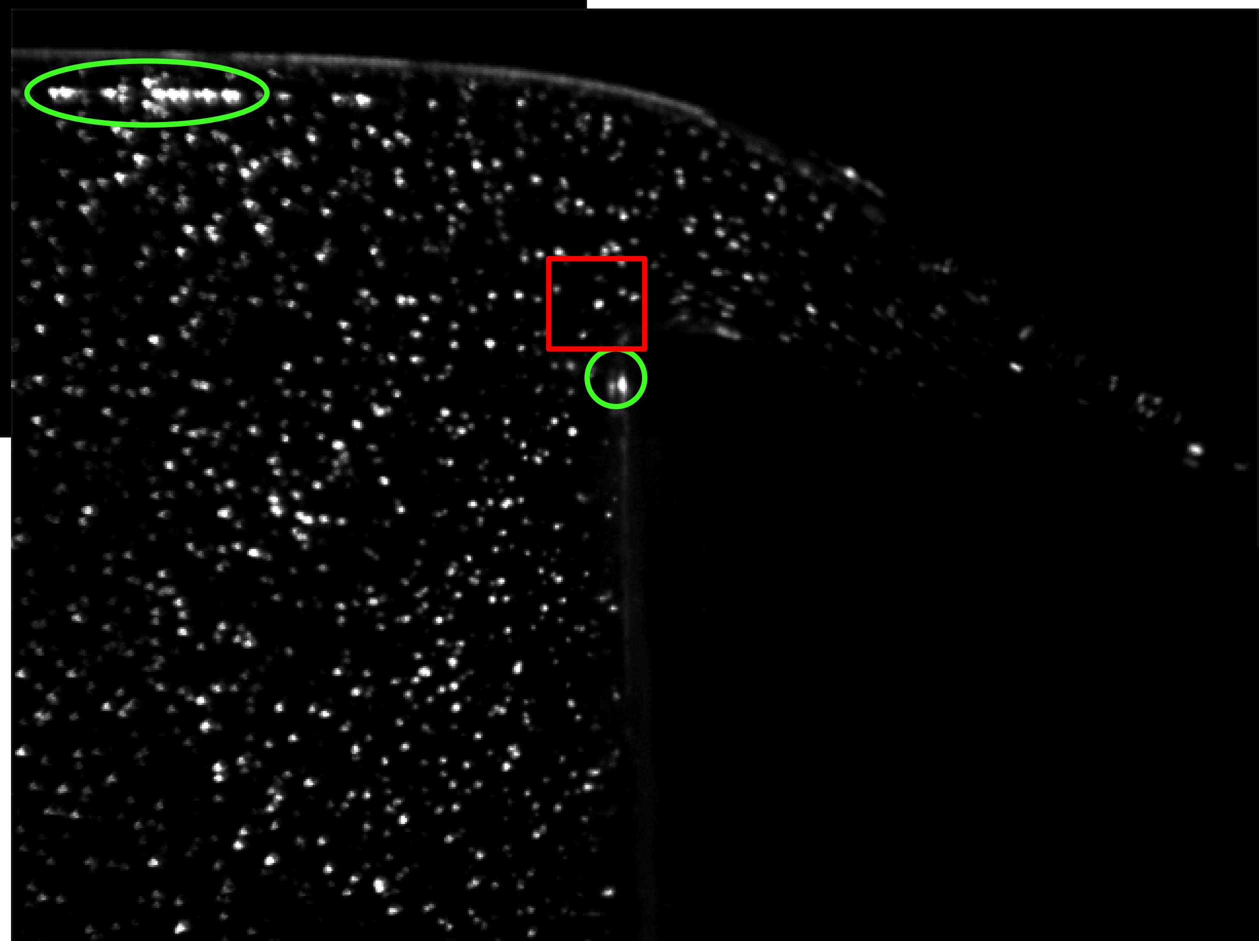
Particle Transport w/o Velocity Vectors





Particle motion 1/1

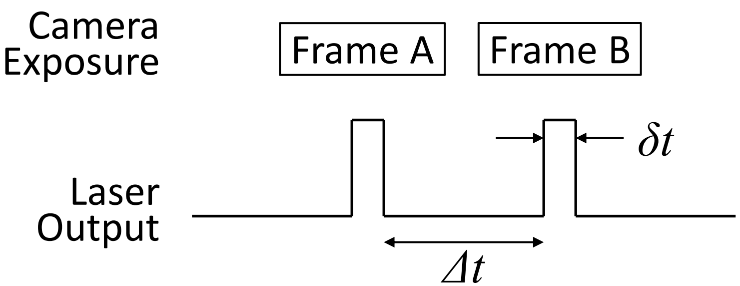
Particle motion 1/2

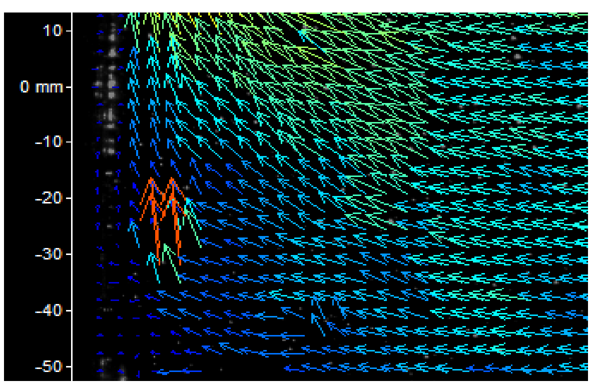


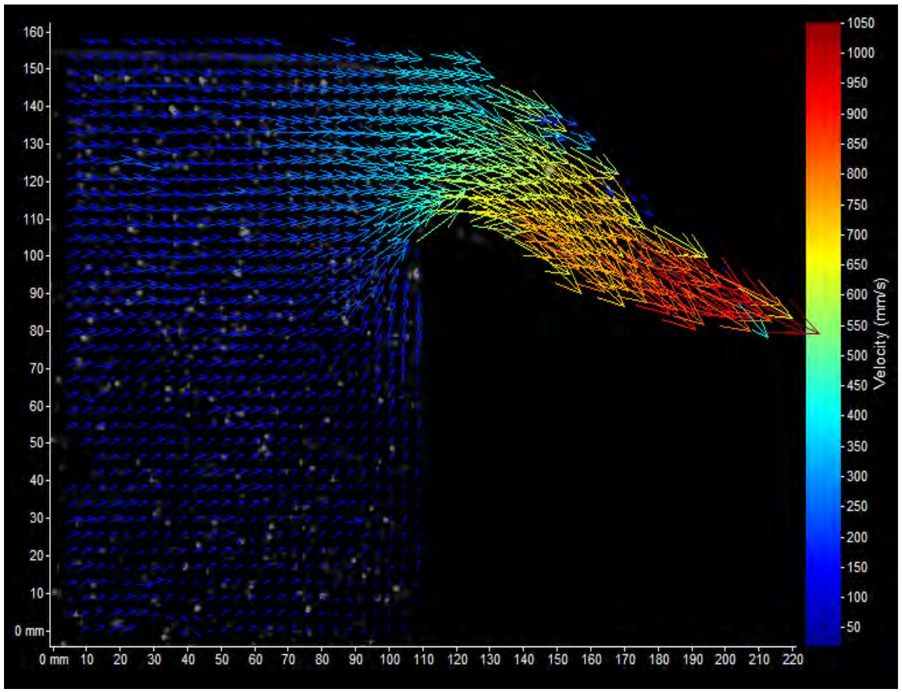
Test Runs and Model Scenarios

PIV Data Filtrations

- Global Velocity Limitation: to establish upper and lower limits for the x and y velocity components
- Neighborhood Method: to compare surrounding 8 neighborhood vectors
- Velocity Zone Separation: to assign different pulse separation and width

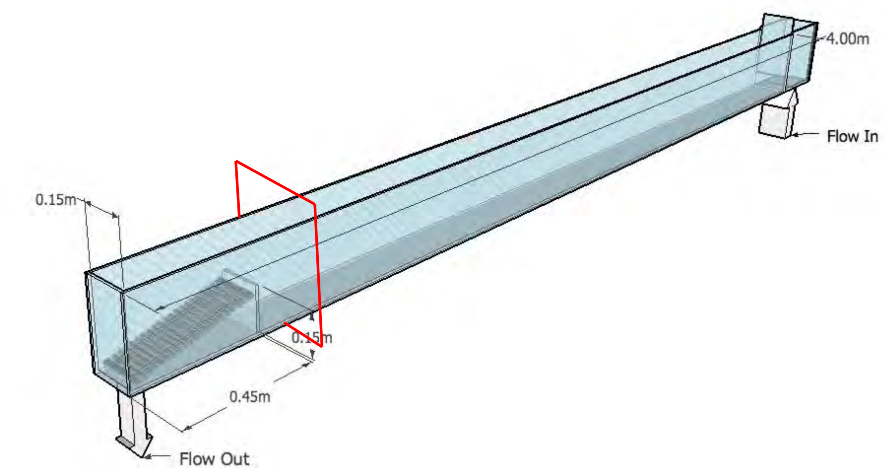


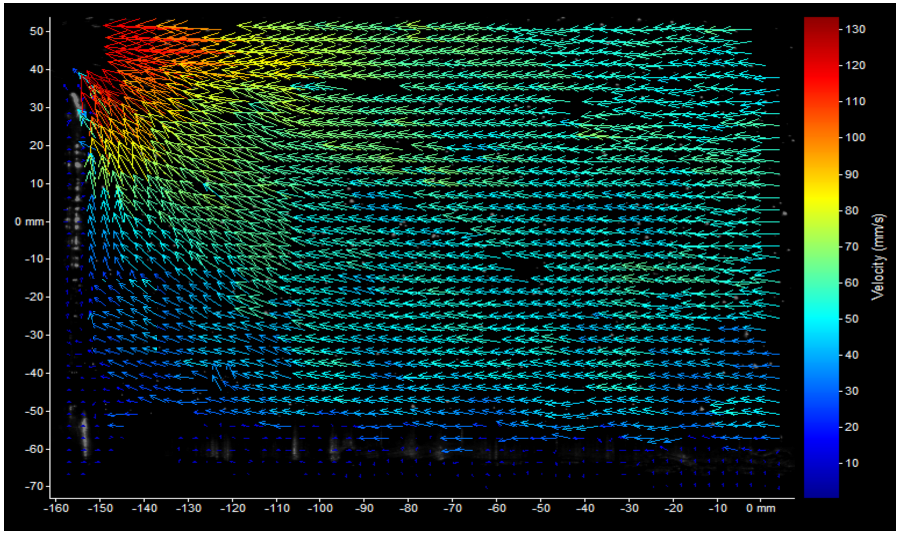




Test Runs and Model Scenarios

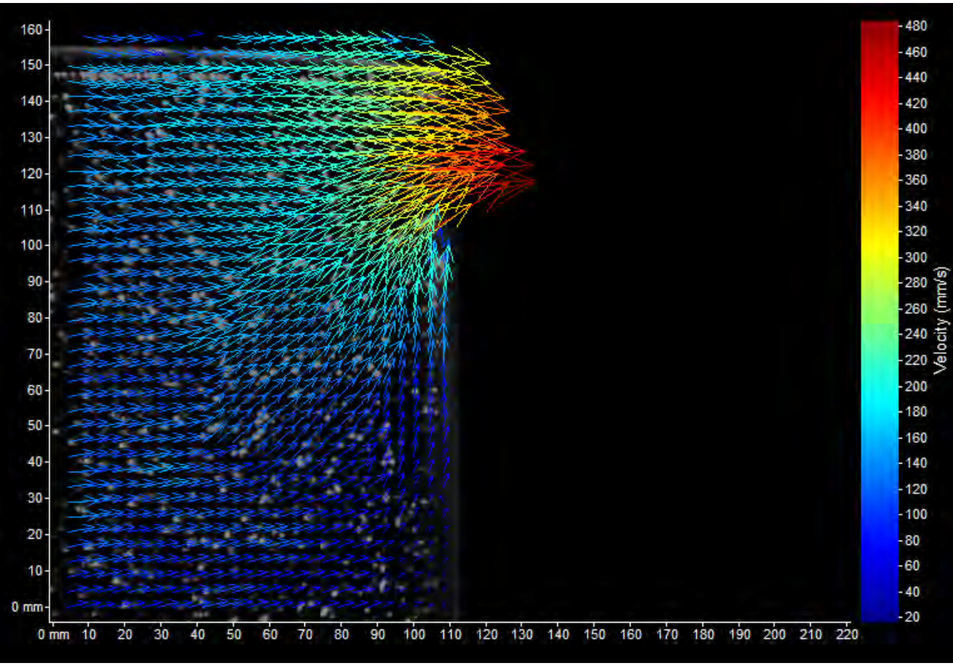
PIV Test Runs: Comparing PIV results with manually measured flume velocities

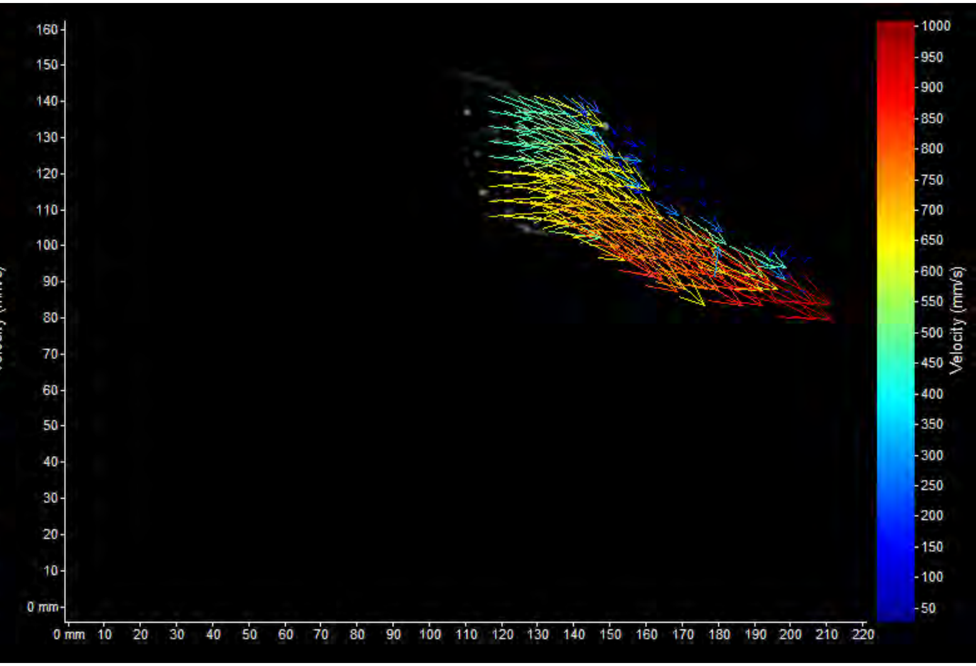




Flow rate (m^3/s)	Velocity (m/s)		Error (%)
	PIV measurements	Manual Observations	
7.25×10^{-3}	0.037	0.041	10.8
1.02×10^{-2}	0.048	0.053	10.4
1.47×10^{-2}	0.066	0.073	10.6

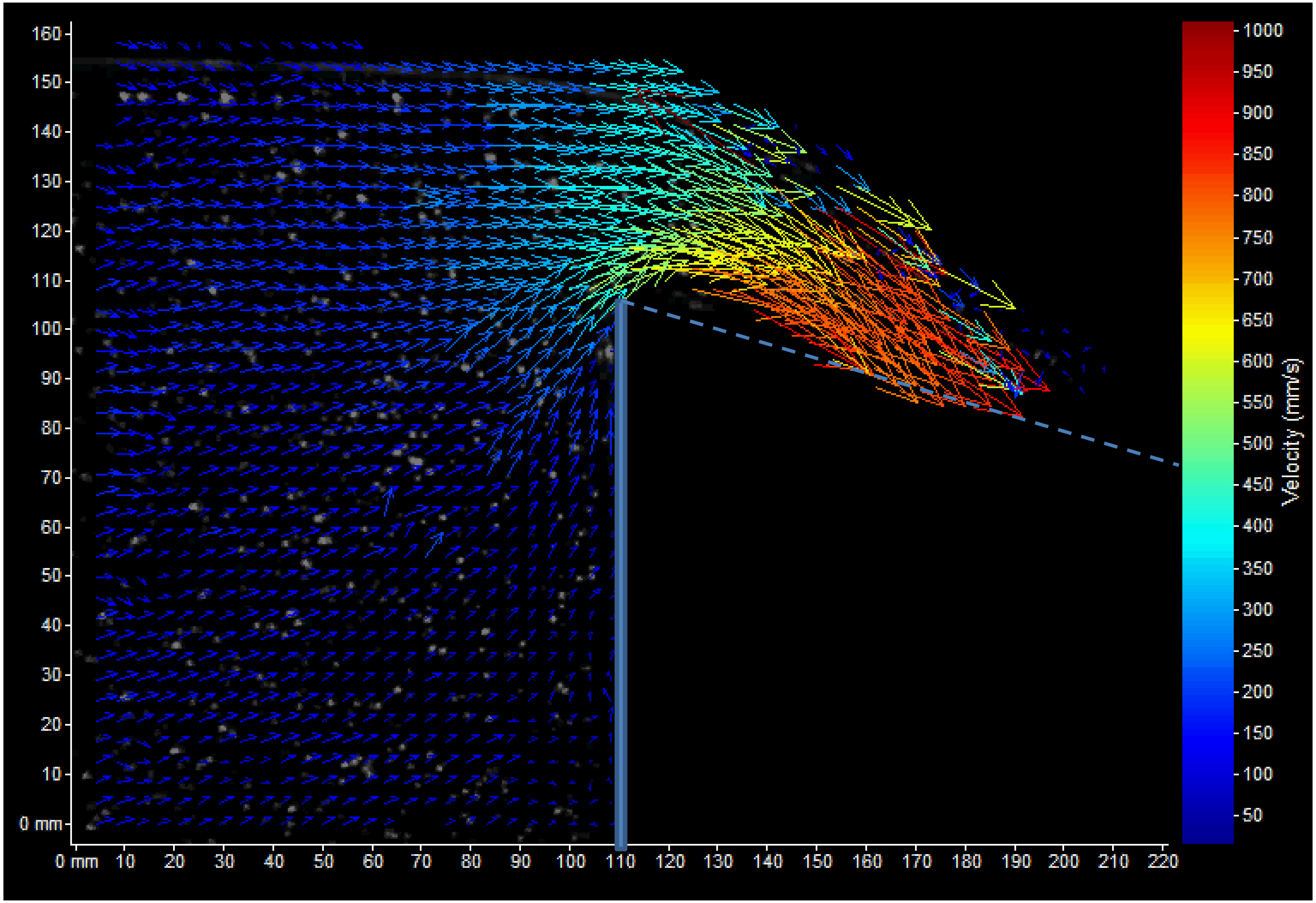
Test Runs and Model Scenarios





		Hardware Setup		Vector Configuration			Vector Filtration			Velocity for Each Point (mm/s)			
Flow Cond.	Frame	Pulse Separation (ms)	Pulse Width (ms)	Initial Pass (Px)	Final Window (Px)	Ovelap (50%)	Maximum Vector (mm/s)	Mean ±RMS	Replace	Flume1	Flume2	Screen1	R2
High	A&B	2.9	2.2	64	24	50	1200	1.29	Yes	145.20	157.09	841.00	800.74
	A	6	5	64	24	50	550	1.29	Yes	135.32	159.35		
	B	2.82	2.18	64	24	50	1100	1.29	Yes			633.49	805.91
Medium	A&B	3.2	2.3	64	24	50	900	1.29	Yes	98.07	108.79	411.81	602.82
	A	6.5	5.5	64	24	50	400	1.29	Yes	91.05	99.27		
	B	2.99	2.33	64	24	50	900	1.29	Yes			338.43	636.37
Low	A&B	4.1	3.1	64	24	50	650	1.29	Yes	45.83	58.69	38.45	348.77
	A	7	6	64	24	50	260	1.29	Yes	48.84	58.57		
	B	3.4	2.5	64	24	50	650	1.29	Yes			18.90	282.67

Particle Transport w/ Velocity Vectors



Numerical Model Simulation

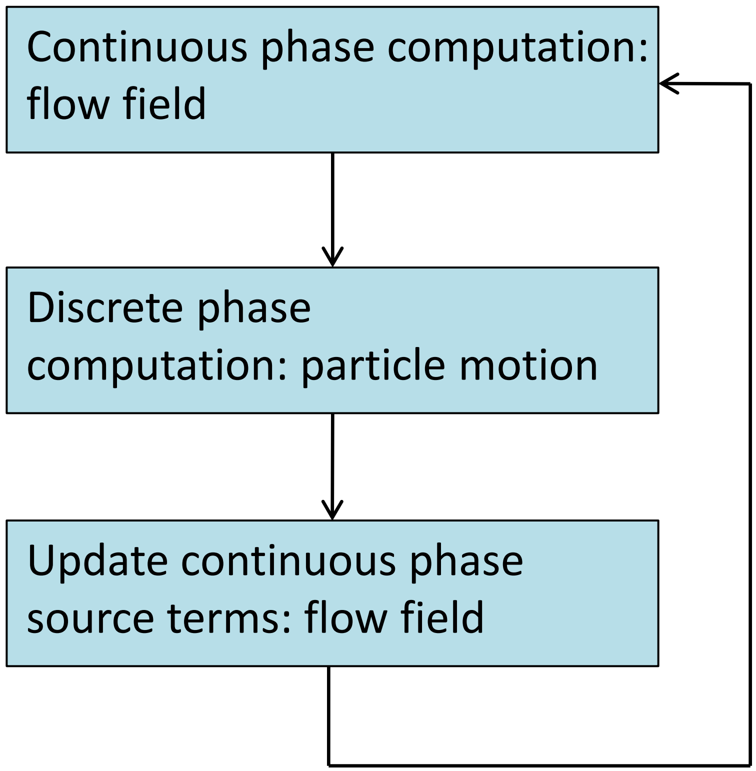
1. To simulate greater scale model to achieve Coanda-effect screen surface velocities without geometric limitations
2. Computational Fluid Dynamics model
    - RANS (Reynolds-Average Navier Stokes) equations
    - Two-dimensional Finite Volume Method
    - VOF (Volume Of Fluid) for fluid-obstacle interfaces
    - Stereolithographic file (stl) format for coanda-effect screen geometry
    - The Prandtl mixing length model for shear stress boundary
    - The incompressible SOR (Successive Over-Relaxation) iteration
    - Discrete phase model for particle transport

Discrete Phase Model

Particle trajectory is calculated by integrating particle force balance as,

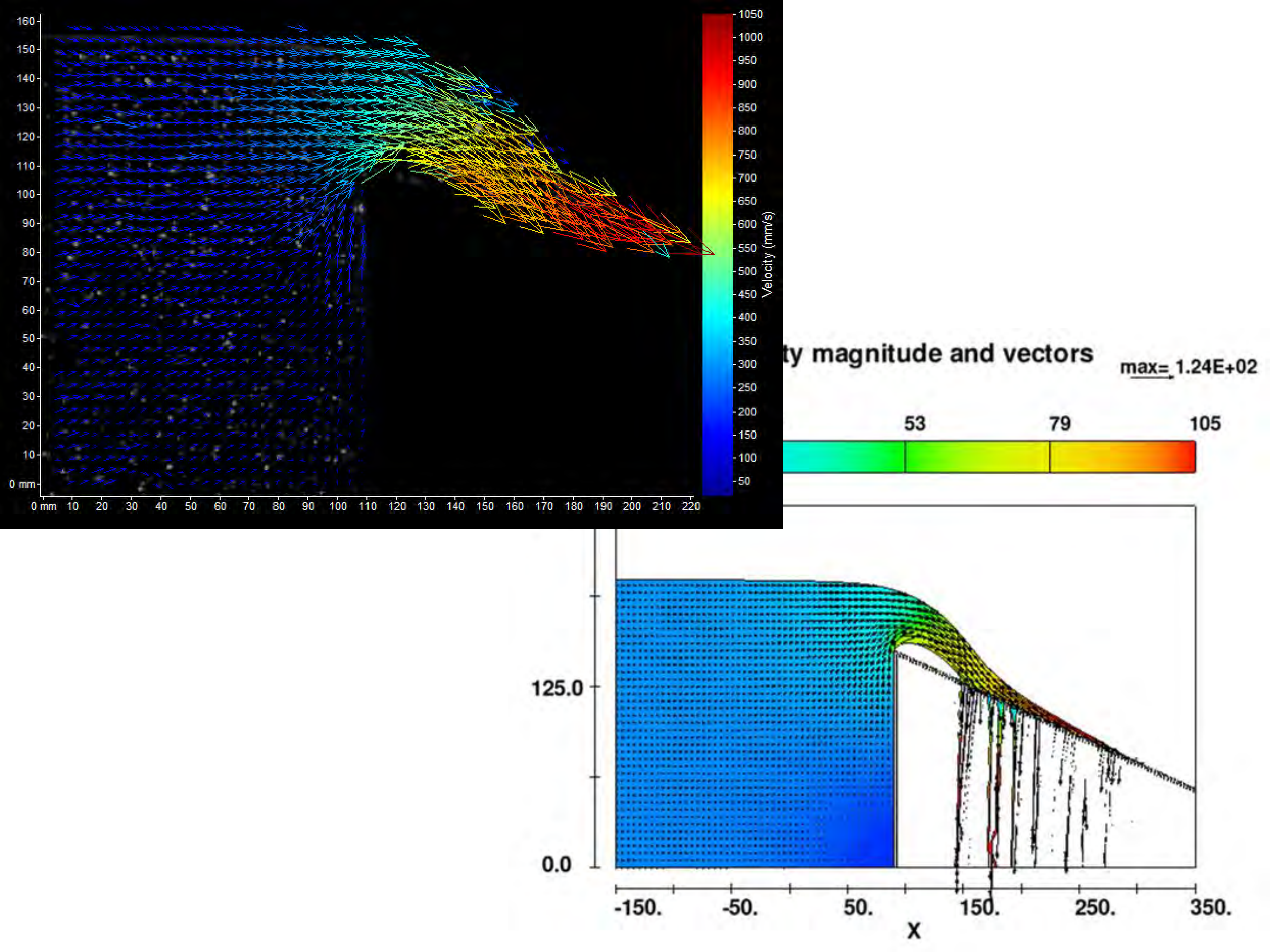
$$\frac{\mathrm{d}u_p}{\mathrm{d}t} = \frac{3\rho}{4 d_p \rho_p} C_D (u - u')|u - u'| - \frac{1}{\rho_p}\nabla P + \frac{(\rho - \rho_p)}{\rho_p} g$$

↑ drag force ↑ pressure gradient ↑ gravity force

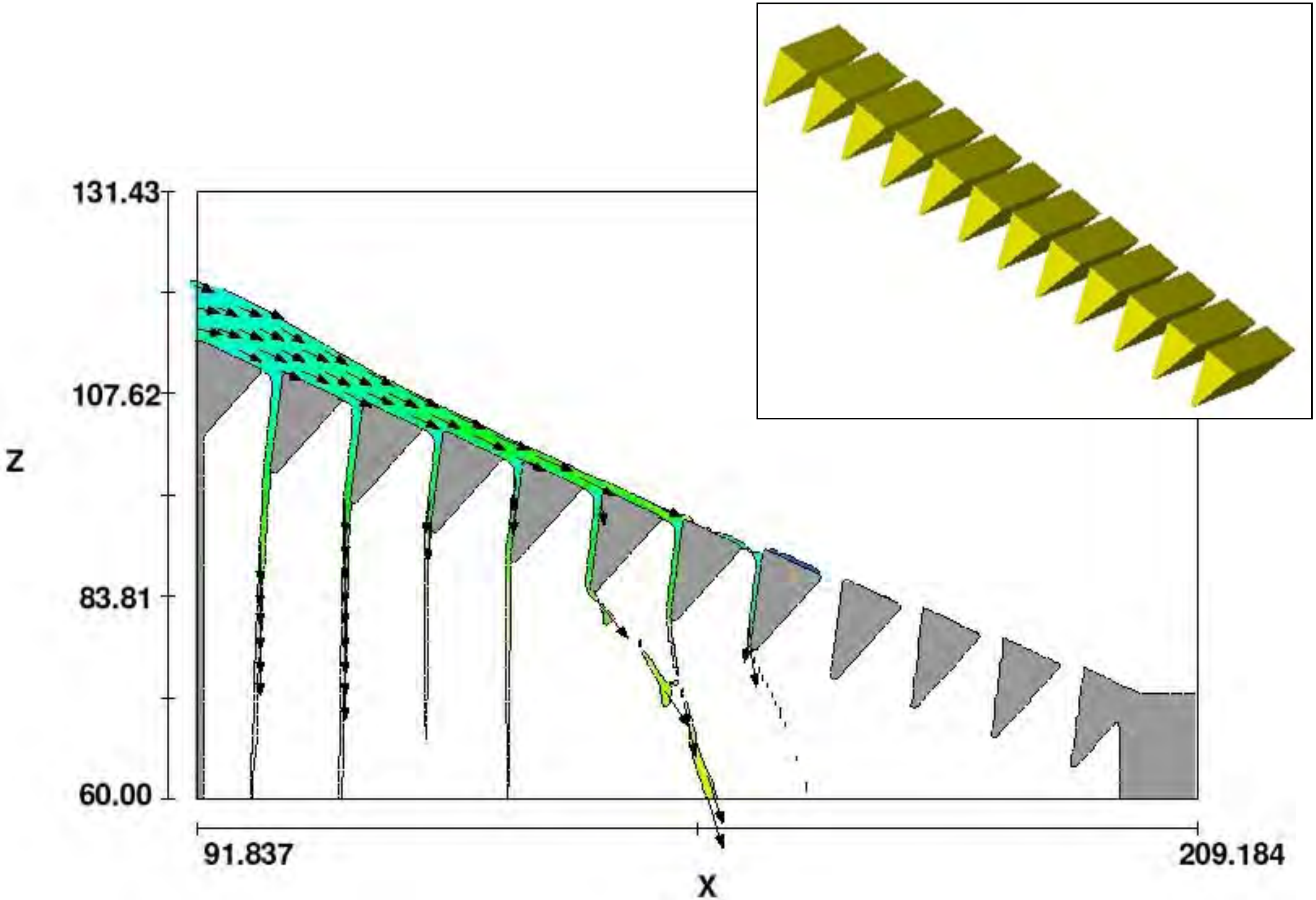


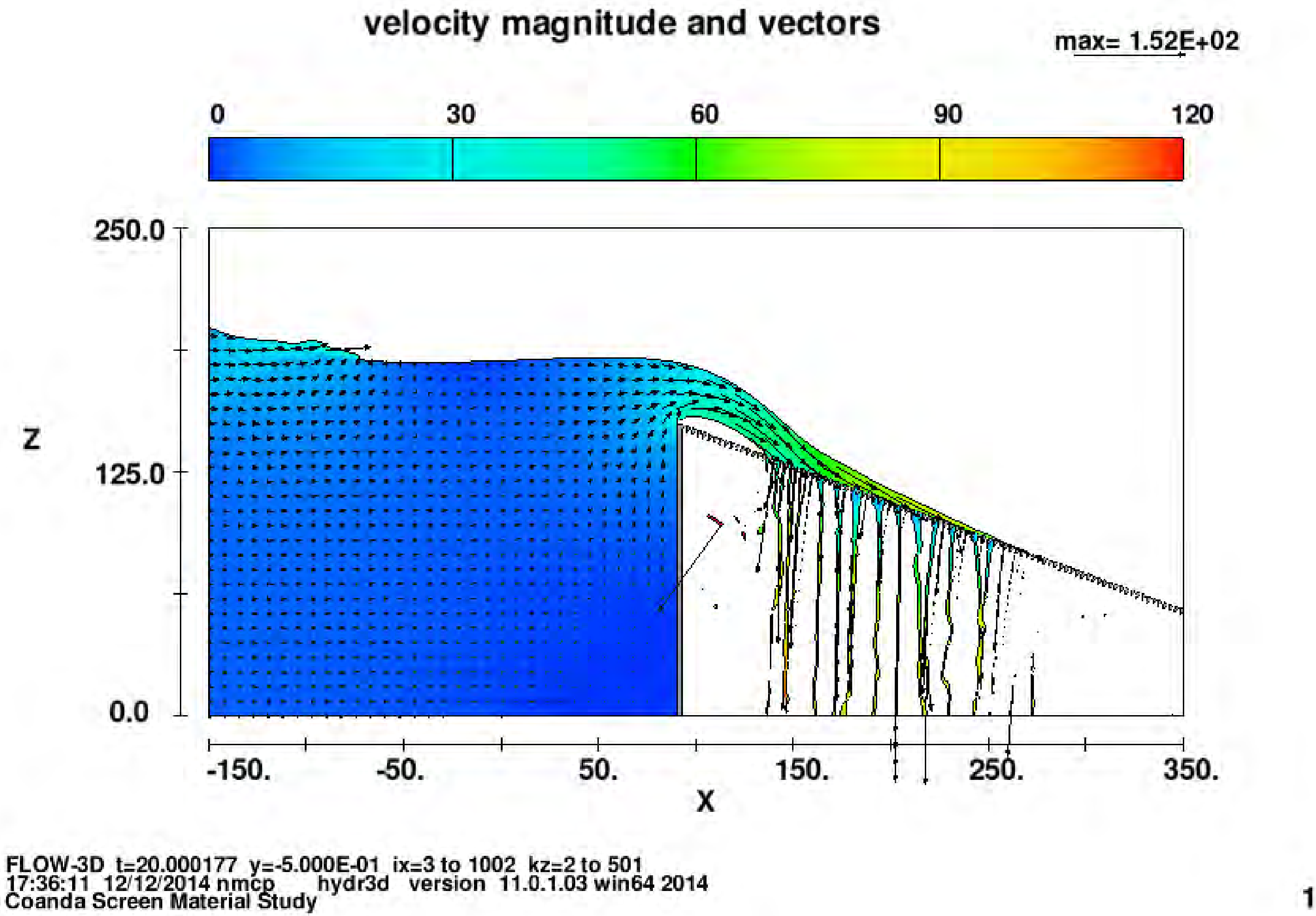
Discrete phase model: Lagrangian frame
Continuous phase model: Eulerian frame

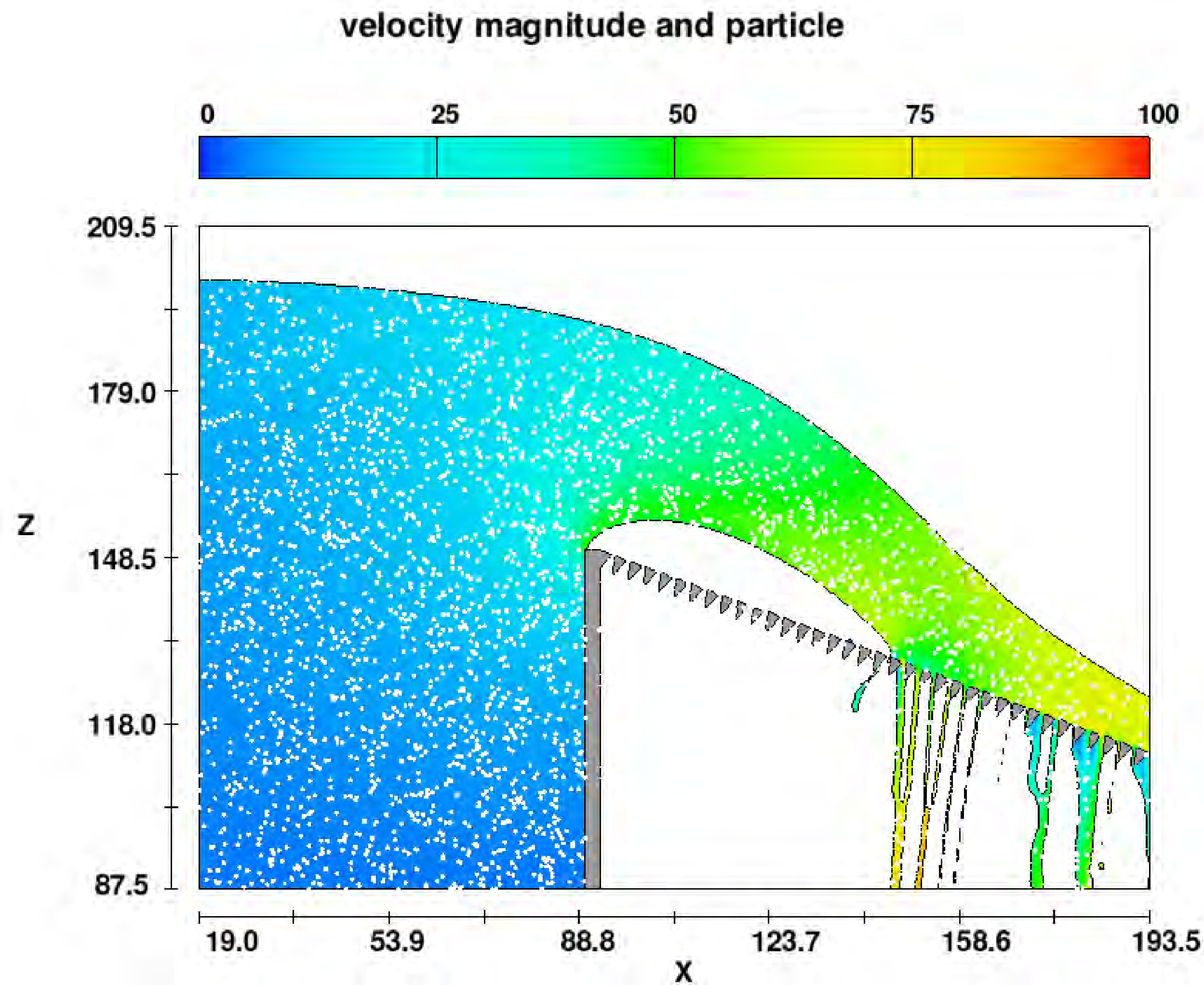
Sediment transport: Eulerian-Eulerian


Velocity (mm/s)
ty magnitude and vectors
max= 1.24E+02
53
79
105
125.0
0.0
-150.
-50.
50.
150.
250.
350.
X

Velocity Vectors on Coanda-Effect Screen




velocity magnitude and vectors
max= 1.52E+02
0
30
60
90
120
250.0
Z
125.0
0.0
-150.
-50.
50.
150.
250.
350.
X
FLOW-3D t=20.000177 y=-5.000E-01 ix=3 to 1002 kz=2 to 501
17:36:11 12/12/2014 nmcp hydr3d version 11.0.1.03 win64 2014
Coanda Screen Material Study
1



FLOW-3D t=40.000145 y=-5.000E-01 ix=341 to 689 kz=177 to 420
17:36:11 12/12/2014 nmcp hydr3d version 11.0.1.03 win64 2014
Coanda Screen Material Study

Comparisons

Flowrate (m^3/s)	PIV Measurements (mm/s)		CFD Computations (mm/s)		PBIAS (%)	
	Flume	Screen	Flume	Screen	Flume	Screen
7.25×10^{-3}	0.037	0.341	0.041	0.430	-10.8	-26.1
1.02×10^{-2}	0.048	0.425	0.053	0.484	-10.4	-13.9
1.47×10^{-2}	0.066	0.461	0.073	0.566	-10.6	-22.8

$$PBIAS(\%) = \frac{\sum_{i=1}^{n}\left(Q_i^{obs} - Q_i^{com}\right)\times 100}{\sum_{i=1}^{n}\left(Q_i^{obs}\right)}$$

Percentage bias (PBIAS): measures the average tendency of the simulated values to be larger or smaller than their observed values.

- Optimal value: 0.0
- Underestimation: < 0
- Overestimation: > 0

Summary and Acknowledgement

1. PIV application to measure surface velocity on coanda-effect screen
2. Good agreements with CFD computations
3. Dimensional analysis to develop coanda-effect screen performance equation (flowrate)

Technical supports: Tony Wahl, P.E. (WRRL, USBR)

Steve Esmond, P.E. www.coanda.com

Appendix D

Steven E. Esmond and Robert K. Weir, “Nutrient Removal Using Coanda Screens,” Presented at StormCon 2018, Denver CO, August 15, 2018, Session B64. This technical report is a summary and synthesis the research done in Melbourne, Australia; also by the University of Southern California; also by the City of Rowlett, Texas; also by Texas A&M University Civil Engineering Department masters thesis on the topic of nutrient removal in Coanda Screens.

NUTRIENT REMOVAL USING COANDA SCREENS

Steven E. Esmond and Robert K. Weir

August 2018

INTRODUCTION

Tilted wedgewire Coanda Screens have been used for decades in the hydropower and agricultural industries. Their small openings, typically 0.5 to 1.0 mm, have gained increasing favor for use in removing urban trash and gross solids. The efficacy of the Coanda Screens in treating storm water has been confirmed by third party testing agencies, including one Federal agency which concluded: “These screens have large flow capacities and are hydraulically self-cleaning without moving parts, so they require minimal maintenance.”[1]

The authors have pioneered the use of Coanda Screens specifically to remove trash and sediment from stormwater runoff. The goal was to create a non-clogging, maintenance-free device that would remove trash from urban storm water. This technology has performed exactly as designed, and has been successfully implemented throughout the US and in the international marketplace.

Early testing revealed that pollutants other than trash and sediment were being removed. Urban stormwater runoff is known to contain solids, nutrients, heavy metals, bacteria, and varied pollutants, which negatively impact the water quality of receiving streams. Stormwater best management practices (BMP) employ both structural and non-structural controls to achieve predetermined water quality goals.

The ability of Coanda-effect Screens to remove nutrients from stormwater has been evaluated in different settings and at various locations. The purpose of this paper is to synthesize summaries the results, so that engineers and planners may have tools to evaluate water quality improvement when employing Coanda Screens.

The nutrients of primary interest in this study are nitrogen and phosphorus. The affinity of both nutrients and heavy metals to associate with particulate matter has been well documented through both research and field experience. Current approaches to gross solids removal have focused on the 5 mm mesh size, some regulatory jurisdictions such as the State of California have adopted 5 mm mesh size as the definition for full capture removal of trash from urban runoff.

The mere act of extracting such small particles from storm runoff not only removes trash, debris and suspended solids, but also a certain percentage of nitrogen and phosphorus associated with particulate matter. This study seeks to quantify the removal of both nitrogen and phosphorus in storm water runoff by Coanda Screens.

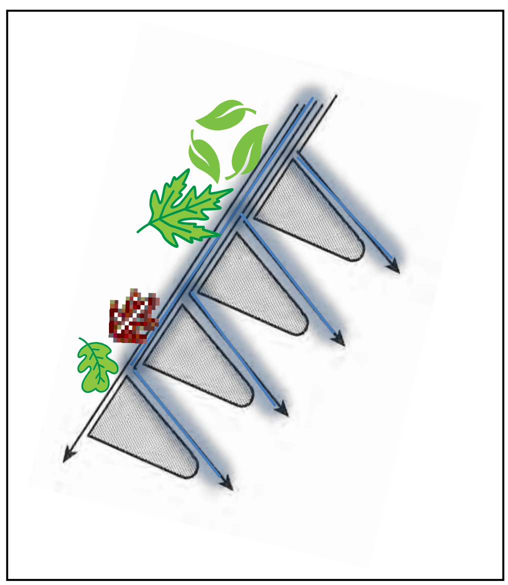


Figure 1. Cross Section of Coanda Screen

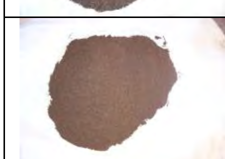
Presented at StormCon 2018, Denver CO, August 15, 2018, Session B64.

WORKING PRINCIPLE
The Coanda-Effect, named after the Romanian aerodynamics pioneer Henri Coanda, describes the tendency of a fluid stream to adhere to the surface of a solid object that is placed in its path of flow.[2] As practiced in the storm water industry, shearing action also plays a part in diverting water through the screen while pushing debris past the openings of the Coanda Screen. The Coanda Effect is key to what differentiates Coanda Screens from conventional screening devices. They are very unlike other screens, in that they do not separate solids from water, but separate water from solids. Thus, water and solids are not forced to compete for the same screen openings. The Coanda-Effect also dramatically increases water velocity through the opening, helping to clean the screen, hence its self-cleaning property.[3] Refer to the graphic in Figure 1.

LITERATURE REVIEW
In a study conducted in Melbourne, Australia, it was found that particulate organic nitrogen constituted 16% of the total nitrogen in base flows and 23% in stormwater runoff.[4] Researchers have demonstrated a positive correlation between organic carbon and nitrate in different media.[5] Altabet found that particulate nitrogen in sea water was found to be mostly associated with particles in the size range of 150-300 μm.[6]

USC STUDY
The University of Southern California (USC) performed field testing, using influent and effluent sampling, to establish up to 80% removal of nitrogen by Coanda Screens.[7] Other pollutants were

Table 1. USC Study of Coanda Screens Debris Analysis

	Description	Sieve Size, mm	% by Wt.
	Woody material (limbs, branches, twigs)		7
	Debris and leafy material (leaves, mulch, grass, fine bark)		44
	Rocks and pebbles	> 5 mm	11
	Coarse sand	>1 to <5 mm	32
	Medium sand	< 1 mm	6
	TOTAL		100

removed as well. The watershed in the USC study was an urban environment consisting of hardscapes, office buildings, sidewalks, streets, small lawns and planters. Approximately 32% of the total weight removed was less than 5.0 mm, and only 6% was less than 1.0 mm.

ROWLETT, TEXAS STUDY

Researchers in North Texas collected samples from a full-scale operating Coanda Curb Inlet BMP over the period of two years.[8] The setting is a primarily residential neighborhood consisting of manicured lawns and gardens, trees, single family residential buildings, sidewalks, and streets. During the two-year period, the BMP captured urban debris consisting mostly of leaves, grass, sand and rocks mixed with anthropogenic trash (discarded packages, cigarette butts, food scraps, etc). The observed capture rate was 22 cu.ft. per acre per year, consisting of mostly leafy material with some tree bark, sand, and urban debris having an average gross bulk density of 15 pcf. The unit removed significant amounts of nutrients, arsenic, and other water quality pollutants, including COD, As, Cd, Cu, Pb, Ni, and Zn. The average removal efficiency over the two-year period was 30% for nitrogen and 10% for phosphorus. Throughout the two-year study, the Coanda screens captured all debris, bypassed no flow or debris, and continuously cleaned the water. But most importantly, the Coanda Screens never plugged or overflowed, nor did they require any maintenance except for semi-annual trash pickup by Vactor truck.

TEXAS A&M UNIVERSITY STUDY

A pilot-scale study was performed by Texas A&M University. Coanda Screens were tested for nutrient reduction capability at flowrates representative of small to medium sized storm runoff events in McAllen, Texas.

Figure 2. McAuliffe RDF Coanda Screen

The City of McAllen, Texas installed a Coanda Channel Screen during the summer of 2012. This regional storm water treatment facility is located on a major tributary of the Arroyo Colorado River, which is a 53 mile watershed draining from west to east in South Texas, emptying in the Gulf of Mexico north of the Rio Grande River. The facility was designed to treat storm water runoff in the McAuliffe Watershed in McAllen. Known as the McAuliffe Stormwater Regional Detention Facility, this treatment facility was equipped with Coanda Screens designed to remove solids at flow rates up to 50 cfs. The Coanda screens at this facility have openings of 0.5 mm, which enables removal of all trash and gross solids greater than 500µ at all low to moderate stream flows. The facility was constructed in an existing 12 foot wide earthen channel, which flows at water depths of one foot during most of the year. Refer to Figure 2 and Figure 3.

Similar channel screen installations have been built across the US in both earthen and lined channels, with varying hydraulic capacities exceeding 1,000 cfs. The largest Coanda Channel

Screen facility in the US is in Albuquerque, NM, designed to remove solids at flows as high as 1,200 cfs.[9]

These screens were also tested in a pilot-scale setup at Texas A&M University-Kingsville for both solids reduction and nutrient reduction at flow rates representative of small to medium sized storm runoff events in McAllen, Texas. The removals of TSS and nutrients were measured at five different hydraulic loading rates, across seven ranges of particle sizes:

- <0.45μ,
- 0.45-1.2μ,
- 1.2-11μ,
- 11-53μ,
- 53-150μ,
- 150-300μ, and
- >300μ.

Removals and removal efficiencies were observed within each range. One of the key questions addressed in this study was to what extent particles less than 500 microns are removed by Coanda Screens.[10] And the main issue in this paper is to what extent are nutrients removed. Another focus area for the paper was to evaluate the removal of nutrients associated with the particles.[11]

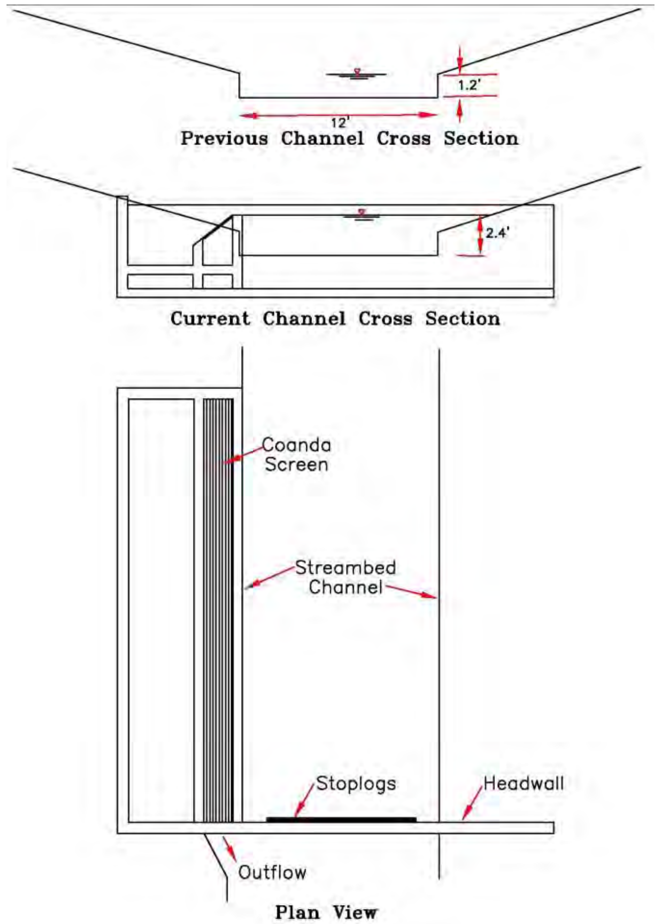


Figure 3. McAuliffe RDF Coanda Screen

DISCUSSION

Storm water was collected from a pond fed by flows from nearby Tranquitas Creek for pilot-scale testing. Water collected from the pond was a mixture of urban storm water and agricultural runoff. This source water has similar water quality with the McAuliffe Channel. Storm water from this pond was transferred by pump to a 500 gallon storage tank. This served as the source for testing the pilot-scale Coanda Screen. This provided a controlled environment and uniform feed concentrations for testing the pilot-scale Coanda Screen at varying flow rates. Both influent and effluent samples were collected, and tested for total nitrogen and total phosphorus among other parameters. Flow rates were adjusted to establish a flux rate across the Coanda Screen of 0.02 cfs/sq.ft. After samples were collected, the flow was increased to 0.04 cfs/sq.ft. so that another representative set of samples could be collected. In the same way, the screen was tested at 0.06, 0.08, and 0.10 cfs/sq.ft.

The results for total nitrogen are shown on Figure 3. It was not anticipated prior to this research that the Coanda Screen would remove significant amounts of nitrogen or phosphorus associated with particles less than 500 microns, which is the size of the openings of this Coanda Screen.

Particles smaller than the screen opening are clearly being removed, attributed to the trajectory of the flow path through the screen. In this case, a measureable amount of particulates as small as 100 microns were removed by the Coanda Screen. There is also some linearity in removal efficiency over the range of particle sizes from 100 to 500 microns.

Results for total phosphorus were similar, as seen in Figure 4. Unlike the removal efficiencies for nitrogen, there was significant removal of phosphorus associated with particles less than 100 microns. Note also the nonlinearity over the range from 0 to 500 microns, similar to what was observed with nitrogen.

This research project also attempted to address the question as to whether removal of nutrients would be a function of flow rate through the Coanda screen. Note the curves in Figure 5, showing average removal efficiencies of both nitrogen and phosphorus were about the same over the full range of flows at which experiments were conducted. The curves indicate the nutrient removal performance of the Coanda Screen is not a function of flow rate. Under normal operation, the Coanda Screen creates both the Coanda Effect, coupled with shearing action at velocities sufficiently high to prevent blockage of the screen openings.[1]

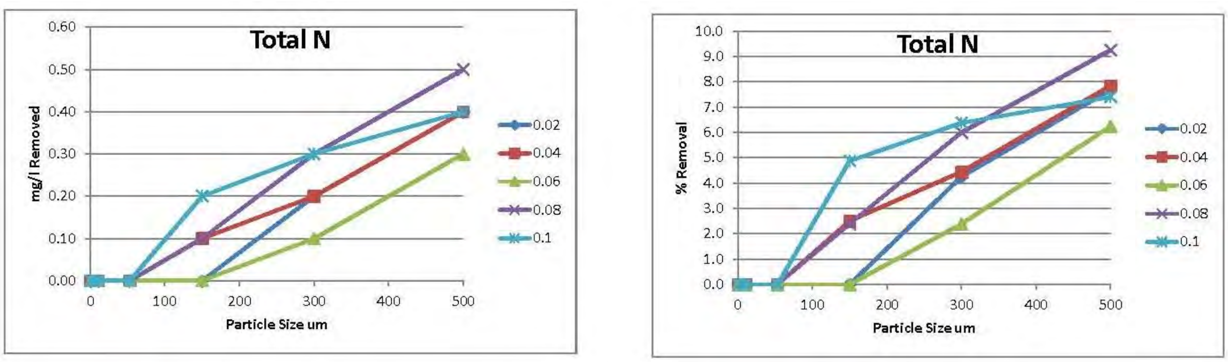


Figure 3. Nitrogen Removal

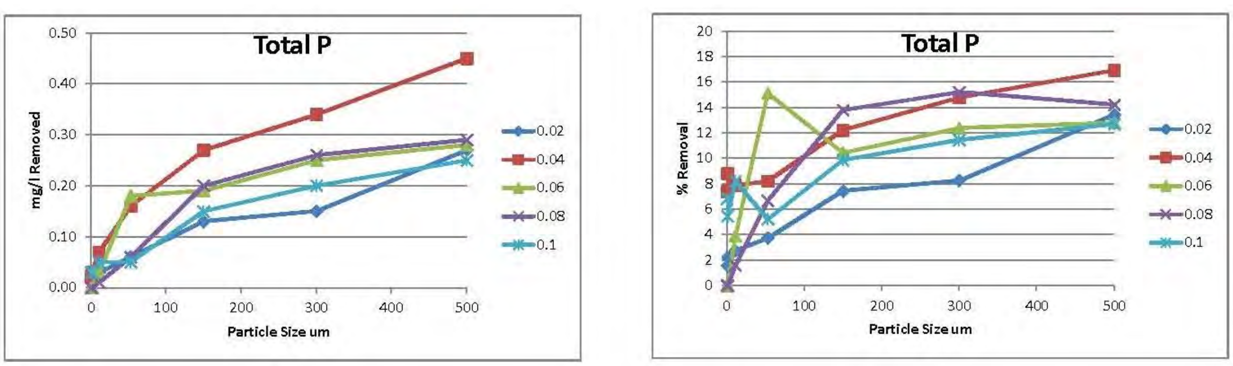


Figure 4. Phosphorus Removal

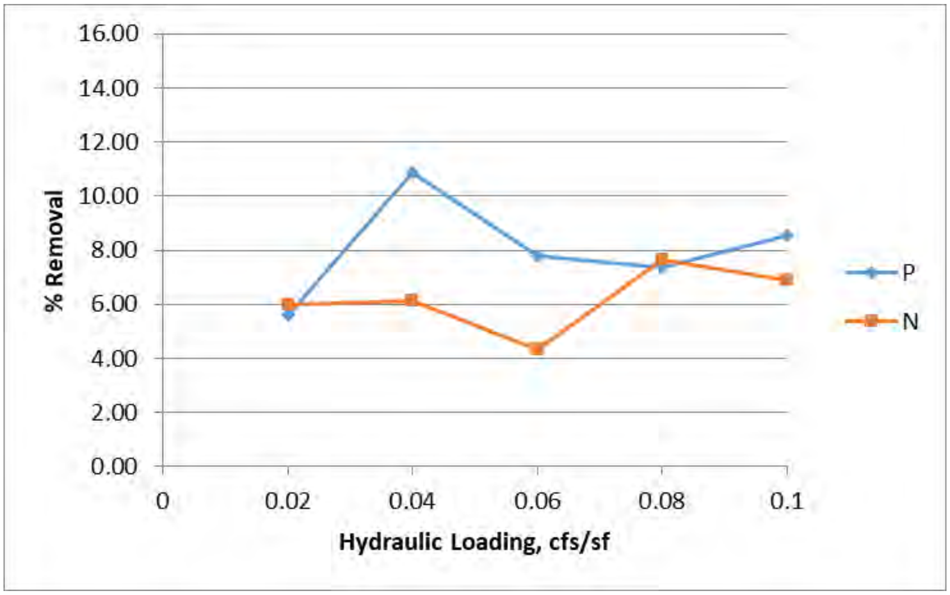


Figure 5. Removal Efficiency vs. Hydraulic Loading

Since hydraulic loading played such a minor part in the removal of nutrients, all of the influent and effluent data for all of the individual tests were combined in the presentation on Figure 6. Here we see influent and effluent concentrations for all hydraulic loadings combined.

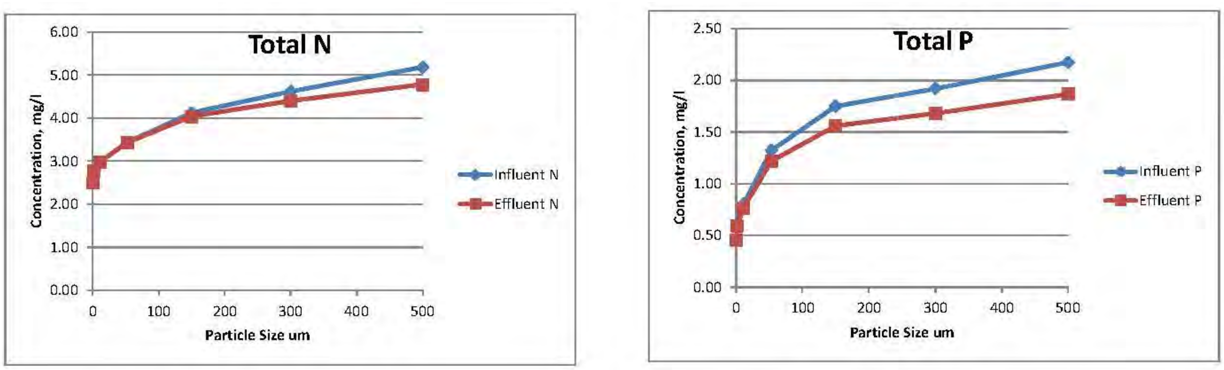


Figure 6. Influent and Effluent N and P

Reduction in nutrient and TSS concentrations at the outlet of the screen showed that it efficiently removed an average of 7.7% of TN, 14% of TP and 18% of TSS. Statistical analysis performed using Wilcoxon's Signed Ranks tests showed that nutrient removal was statistically significant. The removal rates of nutrients bound with particulates <300µ in size were almost unaffected under all five hydraulic loading scenarios which were tested. This research also proved that Coanda Screens are quite capable of removing both solids and nutrients associated with particulate matter in the smaller particle size ranges, significantly smaller than the screen openings.

This study should be interpreted in the context alongside other studies of nutrient removal using Coanda Screens. The statistically significant removal rates are site specific and depend heavily upon conditions and land uses in the watershed. Refer to the comparison on Table 2.

Table 2 – Nutrient Removal Comparison with Other Studies			
	% Removal		Comments
	TN	TP	
University of Southern California	80	(Not Tested)	Highly urbanized environment, mostly office buildings and streets, dominated by anthropogenic trash along with some green waste.
Rowlett, Texas	30	10	Residential land containing lots of green waste and sediment, less anthropogenic trash.
Texas A&M University	8	14	Relatively clean suburban stormwater containing agricultural runoff with algae, small amounts of anthropogenic trash and green waste.

CONCLUSIONS

This paper has provided a synthesis of three independent, peer-reviewed studies, aimed at investigating nutrient removal in stormwater using Coanda Screens. While these screens are intended primarily for separating trash and sediment from stormwater, they provide the added value of removing a certain amount of nutrients and other substances normally regarded as pollutants. Nutrients, like many other chemicals, tend to dissociate into soluble and non-soluble fractions. The non-soluble fraction is typically adsorbed on solids, which the screens remove with great effectiveness.

This paper has quantified the nutrient removal capacity of Coanda Screens in urban stormwater. This collective body of research could be used for planning purposes as well as qualifying the Coanda Screen technology as a nutrient removal device.

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[11] Vinod Balakrishnan, Dr. Kim Jones, and Steven E. Esmond, *Preliminary Results of Nutrient Removal from Simulated Stormwater Runoff Using A Coanda-Effect Screen,* StormCon 2015, Paper R63.

ABOUT THE AUTHORS

Steven E. Esmond, PE, COANDA, Inc., 3943 Irvine Blvd, #327, Irvine, CA 92602, (714) 389-2113, sesmond@coanda.com, web address: www.coanda.com.

Robert K. Weir, PE, Hydroscreen LLC, 2390 Forest St., Denver, CO 80207, (303) 333-6071, rkweir@aol.com, web address: http://www.hydroscreen.com

Appendix E

Mosquito Vector Control Association of California Letter of Verification.

MVCAC
Mosquito and Vector Control Association of California
One Capitol Mall, Suite 800 • Sacramento, CA 95814 • p: (916) 440-0826 • f: (916) 444-7462 • e: mvcac@mvcac.org

Coanda, Inc
3943 Irvine Blvd., #327
Irvine, CA 92602

September 7, 2021

Dear Mr. Esmond,

Thank you for the submitting the Coanda Screens full trash capture devices for review by the Mosquito and Vector Control Association of California pursuant to the SWRCB Trash Treatment Control Device Application Requirements. The Association has carefully reviewed the conceptual drawings for the Coanda Channel Screen, Standard Curb Inlet BMP, Partial Width Isolated Curb Inlet BMP, and Partial Width Open Curb Inlet BMP devices and verifies that provisions have been included in the designs that allow for full visual access to all areas for presence of standing water, and when necessary, allows for treatments of mosquitoes.

While this verification letter confirms that inspection and treatment for the purpose of minimizing mosquito production should be possible with the Coanda Screens full trash capture devices as presented, it does not affect the local mosquito control agency's rights and remedies under the State Mosquito Abatement and Vector Control District Law. For example, if the installed device or the associated stormwater system infrastructure becomes a mosquito breeding source, it may be determined by a local mosquito control agency to be a public nuisance in accordance with California Health and Safety Code sections 2060-2067.

"Public nuisance" means any of the following:

1. Any property, excluding water, that has been artificially altered from its natural condition so that it now supports the development, attraction, or harborage of vectors. The presence of vectors in their developmental stages on a property is prima facie evidence that the property is a public nuisance.
2. Any water that is a breeding place for vectors. The presence of vectors in their developmental stages in the water is prima facie evidence that the water is a public nuisance.
3. Any activity that supports the development, attraction, or harborage of vectors, or that facilitates the introduction or spread of vectors. (Heal. & Saf. Code § 2002 (j).)

Declaration of a facility or property as a public nuisance may result in penalties as provided under the Health and Safety Code. Municipalities and the vendors they work with are encouraged to discuss the design, installation, and maintenance of stormwater trash capture devices with their local mosquito control agency to reduce the potential for disease transmission and public nuisance associated with mosquito production.

Sincerely,

Bob Achermann,

MVCAC Executive Director