An investigation into the design and hydraulic capacity of stormwater trash capture screens

Julia Watson[1], Mike Hannah[1], James Lenhart[2]

[1]EnviroPod [2] Stormwater Northwest LLC

ENVIROPOD.COM INFO@ENVIROPOD.COM

Executive Summary

In 2007 the Country of Los Angeles Department of Public Works published a technical report entitled Connector Pipe Screen Design – Full Capture TMDL (Total Maximum Daily Load) Compliance Screen and Bypass Sizing requirements. The method of calculation in the report comprises the orifice equation to determine flow through the screen with the use of a critical depth equation to determine the depth of tailwater acting on the screen for a given flow rate. This method includes a screen coefficient, or coefficient of discharge, and has been widely adopted for the calculation of flow through catch basin inserts across the industry since. The LA County Report states that the screen coefficient, C, is unique to each orifice geometry and that orifice conditions for screen holes differ substantially from the conditions used to determine standard orifice coefficients. The report also states the coefficient for trash screening devices should be empirically determined for specific geometries, materials and flow conditions.

This report investigates the hydraulic performance of trash screening catch basin inserts, baskets and connector pipe screens, which are vital for compliance with California's trash reduction mandates and Total Maximum Daily Load (TMDL) requirements. These regulations are intended to limit pollution from urban stormwater runoff. Concern has been raised that the application of the single orifice method, i.e. without empirical testing, is substandard and potentially overestimates the hydraulic capacity of catch basin inserts. It should also be noted that flow through basket systems is cross flow which helps to sweep solids from the screen surface to reduce clogging whereas connector pipe screens are typically direct flow which pins solids to the screen surface and increases clogging. Clogging or occlusion factors have not been considered in this study, however would likely reduce the capacity of catch basin inserts further.

This study evaluates and compares four commonly used methods for determining the maximum treatable flow rate (MTFR) and bypass capacity of trash screens. Each method has strengths and weaknesses, and the findings reveal some significant differences in their accuracy and applicability:

1. **Single Orifice Method**: This method, widely used in California and originally applied to connector pipe screens, relies on a simplified orifice equation with a discharge coefficient (C). Although convenient, the Single Orifice Method may oversimplify complex hydraulic interactions, making it less reliable under real-world conditions and especially problematic for catch basin inserts.

2. **Integrated Orifice and Driving Head Method**: This method improves upon the Single Orifice approach by considering individual orifices within a trash screen and the driving head for each row. By factoring in the unique flow characteristics at different heights, it provides a more accurate picture of actual flow conditions, for the screen only.

3. **Stage-Discharge Empirical Testing**: Conducted in controlled laboratory conditions, this method establishes a relationship between water depth (stage) and flow rate (discharge). These stage-discharge relationships, specific to both free discharge and tailwater conditions, provide a reliable measure of screen efficiency and hydraulic performance, aligning more closely with the complex realities of trash screen operation. However, it does not wholly reflect field conditions of site system geometry.

4. **Computational Fluid Dynamics (CFD) Modeling**: CFD simulates the full geometry and flow dynamics of a trash capture system. It allows for the assessment of complex interactions within a catch basin, capturing both inlet and outlet effects in a three-dimensional space. CFD modeling emerged as the most dependable method in this study, as it encompasses the intricate hydraulics that simpler methods overlook.

The study's findings reveal that the Single Orifice Method, which remains widely adopted in the industry, can overestimate a trash screen's hydraulic capacity by up to 250%. This overestimation poses a risk of undersized systems that may not withstand high flow or tailwater conditions, leading to clogging and overflow that compromise stormwater management and pollution control efforts. By contrast, CFD modeling and stage-discharge empirical testing demonstrate higher accuracy, especially under extreme weather scenarios where screen occlusions and bypass limitations are more likely to occur.

The study's results highlight the need for updated regulatory standards that specify the appropriate calculation method for each type of trash capture system, considering both free discharge and tailwater scenarios. Furthermore, the following recommendations are made to improve design reliability:

- **Development of Empirically Based Discharge Coefficients**: Rather than relying on generalized coefficients (e.g., C of 0.61), discharge coefficients should be derived through empirical testing specific to each trash screen's material, geometry, and operational environment. This empirical approach would increase accuracy in flow estimates, especially for customized or unique designs.
- **Implementation of Standardized Safety Factors for a Given Method**: Incorporating a safety factor to account for reduced hydraulic capacity due to geometry and tailwater conditions is crucial. Without these factors, designs will likely underestimate the treatable flow, which is problematic under peak flow conditions. If various calculation methods are going to be used, then each method should have a standardized safety factor based on that method's accuracy to ensure equality across flow calculations regardless of the method used.
- **Mandated Reporting of Hydraulic Capacity at 50% Maximum Trash Capture Volume (MTCV)**: Reporting hydraulic capacity as a percentage of MTCV would provide a more realistic assessment of system performance, particularly in scenarios of partial screen occlusion, ensuring designs remain effective under sub-optimal conditions.

The urgency of these recommendations is underscored by climate projections, which indicate that California could experience a 20-25% increase in extreme precipitation events for a 1-in-10-year storm by 2050. Such intensified rainfall necessitates trash capture systems that are resilient to high flows, providing adequate bypass capacity and treatment flow rates to avoid localized flooding and pollution backflows. If regulatory agencies and manufacturers fail to recalibrate their design and certification approaches to reflect these insights, they may face increased liability due to hydraulic failures of trash capture systems.

Effective trash capture is not only a matter of environmental compliance but also a public safety issue, as inadequate systems contribute to increased flood risk and potential infrastructure damage. This report advocates for a revaluation of trash capture device design standards and the adoption of more rigorous, empirically validated hydraulic design standards. Establishing comprehensive regulatory frameworks will provide consistency in performance expectations, improve public safety, and ensure trash capture systems remain effective in the face of evolving environmental challenges.

Contents

Introduction

Accurate methods for determining the maximum treatable flow rate (MTFR) and bypass capacity of trash screening devices are required to meet California statewide trash amendments and trash total maximum daily loads (TMDL). The accuracy of these methods is becoming increasingly important with the impacts of climate change and flood risk.

A review of the Certified Trash Full Capture Systems Available to the Public on the CASQA website suggests that the methodology used in a technical report written by the LA County (Moon, 2007), which uses the orifice equation, has become a proxy standard for hydraulic design in full trash capture certifications. Concern has been raised that this method overestimates the hydraulic capacity of devices.

This study sets out a comparison of four approaches for determining the capacity of catch basin inserts and screens using numerical and experimental methods. The four methods considered in the evaluation are:

1. **Single Orifice Method**: This method, widely used in California and originally applied to connector pipe screens, relies on a simplified orifice equation with a discharge coefficient (C). Although convenient, the Single Orifice Method may oversimplify complex hydraulic interactions, making it less reliable under real-world conditions and especially problematic for catch basin inserts.
2. **Integrated Orifice and Driving Head Method**: This method improves upon the Single Orifice approach by considering individual orifices within a trash screen and the driving head for each row. By factoring in the unique flow characteristics at different heights, it provides a more accurate picture of actual flow conditions, for the screen only.
3. **Stage-Discharge Empirical Testing**: Conducted in controlled laboratory conditions, this method establishes a relationship between water depth (stage) and flow rate (discharge). These stage-discharge relationships, specific to both free discharge and tailwater conditions, provide a reliable measure of screen efficiency and hydraulic performance, aligning more closely with the complex realities of trash screen operation. However, it does not wholly reflect field conditions of site system geometry.
4. **Computational Fluid Dynamics (CFD) Modeling**: CFD simulates the full geometry and flow dynamics of a trash capture system. It allows for the assessment of complex interactions within a catch basin, capturing both inlet and outlet effects in a three-dimensional space. CFD modeling emerged as the most dependable method in this study, as it encompasses the intricate hydraulics that simpler methods overlook.

Each of these methods is used to determine:

- Flow through a punched stainless-steel screen with 4.8mm holes and 51% open area mounted in a flume under:
    - Free discharge conditions
    - Tail water conditions
- Flow through a standard basket catch basin insert for a 24” x 24” catch basin insert with 2-inch bypass:
    - This is free discharge conditions applied to a device.

In addition, a CFD analysis and culvert inlet design were carried out for a connector pipe screen and catch basin with the dimensions and recommended values provided in the LA County

Report. The purpose was to determine the depth of tailwater acting on the screen and to check for any differences between the LA County single orifice method and the alternative design approaches with the alternative screen when using the LA County design parameters.

The single orifice methods equation uses a coefficient of discharge, C_d, which is essentially a correction factor for any losses encountered at an outlet. The equation is generally applied to a single orifice outlet. Where the equation is being applied to a screen the coefficient should be determined in a laboratory. Laboratory testing was carried out on the 4.8mm stainless steel screen, mounted in a flume under free discharge conditions and in tailwater conditions. For free discharge conditions, the coefficient of discharge (C_e) determined was 0.41 and for tailwater conditions, the C_e was 0.38. Therefore, any calculation requiring a coefficient of discharge will consider the laboratory-derived coefficient, C_e, as a comparison to the industry-adopted coefficient, C_d, of 0.61. Laboratory testing and the coefficient of discharge are further explained in the Laboratory Testing and Calculation Methods sections of this report.

Background

The Concern

The common practice of using the single-orifice method in hydraulic design can significantly overestimate the flow capacity of catch basin insert screen and bypass capacities. This study suggests up to 250% in some cases. This overestimation can lead to underperformance, particularly during high-intensity rainfall events, where the actual flow capacity may fall short of design expectations. The consequence is a heightened risk of trash accumulation and clogging, which can disrupt flow, exacerbate environmental pollution, and pose both flooding and liability risks, especially given the increasing intensity and frequency of rainfall patterns driven by climate change.

Catch Basin Insert Trash Full Capture Technologies

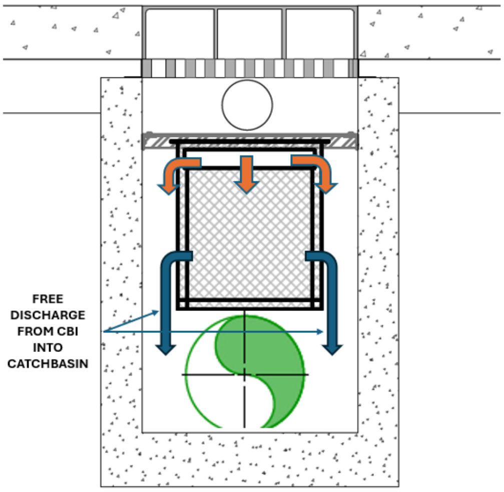
Two popular types of trash full capture catch basin insert devices are connector pipe screens and filter baskets, or baskets. The popularity of such devices can likely be attributed to cost-effectiveness for retrofits and ease of installation and maintenance. They are often used in urban areas to meet environmental regulations and to prevent stormwater system blockages, which can result in surcharges and flooding. Each technology is briefly described below.

Baskets

Catch basin insert baskets are designed to fit inside a storm drain or catch basin near street level. These inserts typically include a basket or filter system designed to screen and capture trash, debris, and other pollutants greater than 5mm in size and prevent them from entering the catch basin sump. The near-street level position means these technologies typically operate in free discharge conditions as they are suspended above the base of the sump and stormwater is allowed to flow through them and into the sump as shown in Figure 1 (left).

Connector Pipe Screens

Connector pipe screens (CPS) devices are fitted over the outlet pipe of a catch basin, within the sump. Like catch basin inserts, these technologies screen trash, debris, and other pollutants greater than 5mm in size. However, the in-sump position of this technology means trash and debris will enter the sump but are prevented from entering the outlet pipe. Connector pipe screens operate in tailwater conditions as opposed to free discharge conditions. This means that while water will back up behind the screen within the sump, there will also be water on the outlet pipe side in front of the screen as shown in Figure 1 (right). The tailwater effect changes the hydraulics of the flow through a screen when compared to a catch basin insert in free discharge conditions.



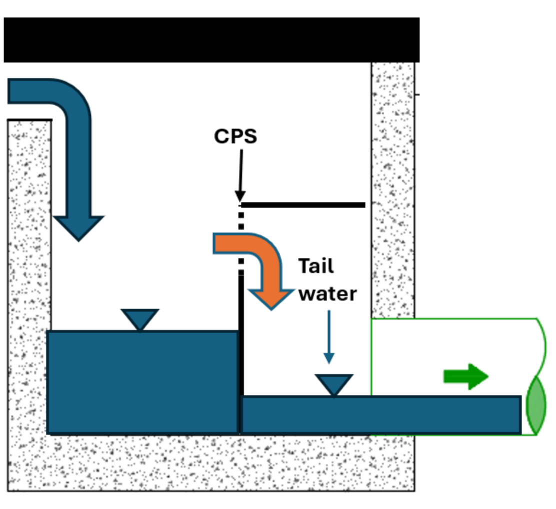


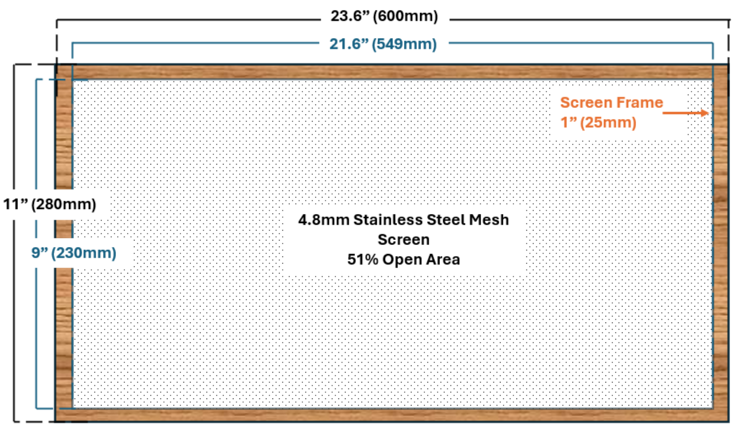
Figure 1 Schematic illustration to show the free discharge flow conditions of a catch basin insert (left) and the tailwater acting on a Connector Pipe Screen (right) in a catch basin. Bypass flow paths are shown in orange.

Bypass flows

Bypass flows are designed into these technologies to prevent flooding in storm flows that are much greater than what the device has been designed for, if the device is clogged and in need of maintenance or is required in the regulations. Bypass flows are typically calculated for a rectangular orifice or weir in free discharge conditions for catch basin inserts and connector pipe screens.

Laboratory Testing

A 4.8mm stainless-steel screen with 51% open area was tested in free discharge conditions and in tailwater conditions within a 23.6" (600mm) wide flume. Free discharge conditions were tested for application to catch basin insert baskets and tail water conditions were tested for application to connector pipe screens. The measurements of the screen are provided in Figure 2.



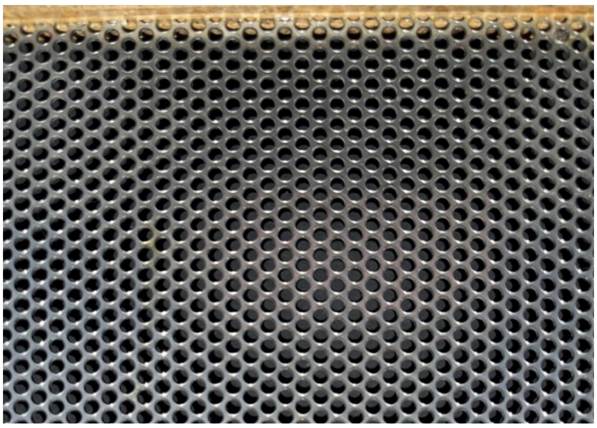


Figure 2 Left: Schematic diagram illustrating the stainless-steel screen test in the flume and used in various comparative calculations Right: photograph of the screen showing 4.8mm holes off center at 60 degrees, with 51% open area and approximately 18.2 holes/in².

Free Discharge Conditions

This test was carried out to allow a comparison of empirically derived data for the screen with the single orifice and integrated orifice and driving head calculation methods in free discharge conditions. The scenario is also modeled in CFD to compare with actual data and calculated results.

Laboratory Configuration

For free discharge conditions, the screen was placed at the end of the flume as shown in Figure 3. The water surface elevation was measured behind the screen for multiple flow rates to allow the development of a stage discharge curve to calculate the hydraulic efficiency of the screen in free discharge conditions. This testing is discussed further in the Stage-Discharge Method section and in the CFD modeling section.

Applied model

Data from this test apply to calculations for catch basin inserts, therefore the data are applied to a stainless-steel catch basin insert with the dimensions shown in

Figure 4. This catch basin insert is designed for 24"x 24" catch basin and the purpose of an applied model is to enable a comparison between all calculation methods when each is applied to the same scenario.

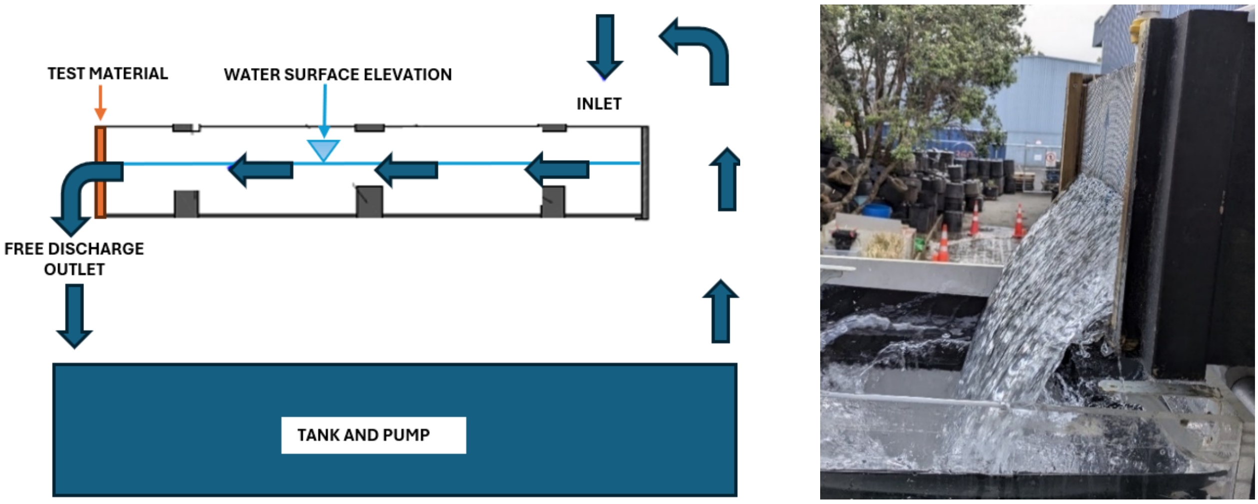


Figure 3 (left) Schematic of the laboratory set up for the free discharge testing (right) photo of water free discharge from flume and through screen during testing.

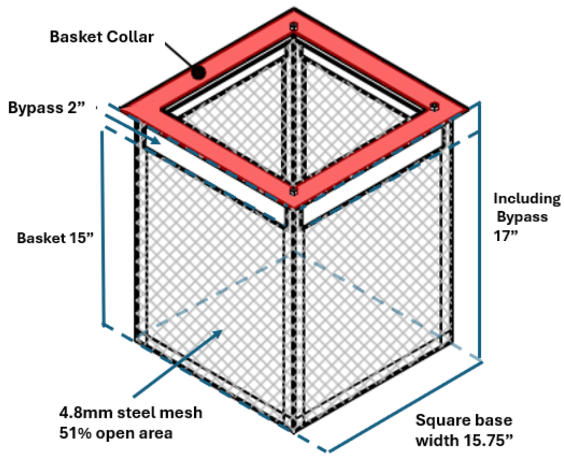


Figure 4 Schematic illustrates the stainless-steel catch basin insert for which the treatment flow rate will be calculated using all methods as a comparison.

Tailwater Conditions

This test was carried out to allow comparison of empirically derived data with the single orifice method, the CFD data in tail water conditions.

Lab set up

For tailwater conditions the screen was placed at the center of the flume as shown in Figure 5. The water surface elevation was measured upstream of the testing material as well as downstream for multiple flow rates to allow the development of stage-discharge curve to calculate the hydraulic efficiency of the screen in tailwater conditions.

Applied model

Data from this test apply to a connector pipe screen. Firstly, each of the four methods were applied to the screen in flume as a basic comparative measure for each approach. Secondly, the data were used to determine the tailwater conditions for a connector pipe screen with the geometry shown in Figure 6. The connector pipe screen is designed for a 7-foot curb inlet catch basin in accordance with the data provided in the LA County Technical report (Moon, 2007). The purpose of an applied model is to determine the tailwater depth acting on the connector pipe screen. The methods used for the full-scale connector pipe screen are detailed further in the section entitled 'Connector Pipe Screen'.

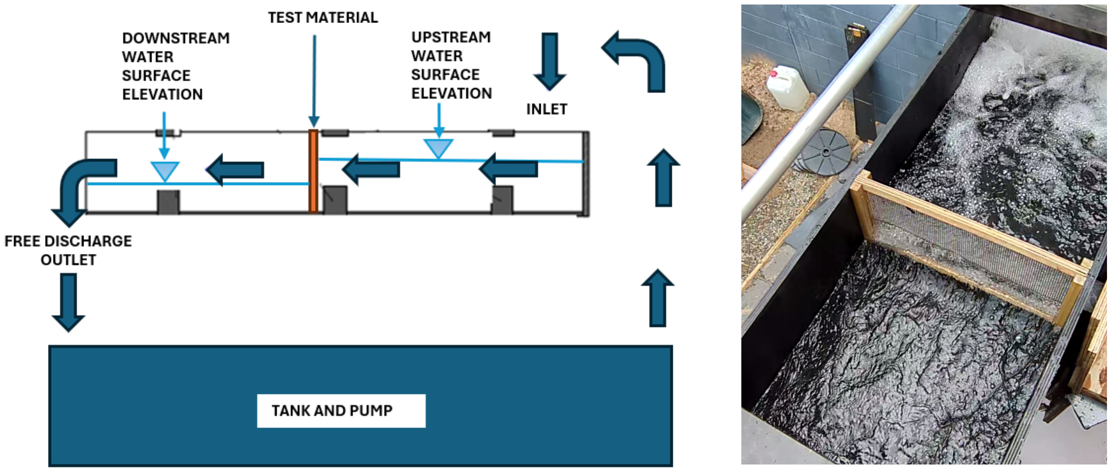


Figure 5 Schematic of the laboratory set up for the tailwater testing (left) photo of water flowing through the screen in the flume during testing (right).

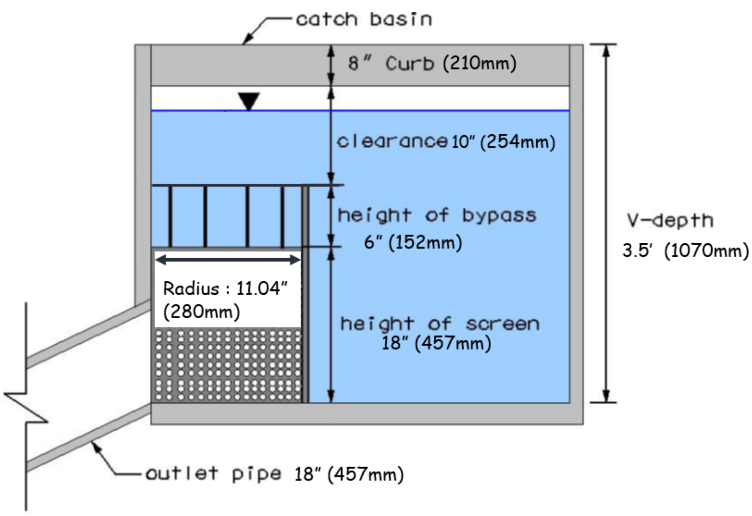


Figure 6 Connector pipe screen and catch basin geometry. Taken and adapted from the LA County CPS Technical Report (Moon, 2007)

Calculation Methods

Single Orifice Calculation Method/ LA Country Method – Public Works Report

Description

The LA County Public Works method (Moon, 2007) uses the orifice equation and was originally developed for the Los Angeles (LA) trash Total Maximum Daily Load (TMDL) when the statewide regulation was made. The LA County applied this method to a connector pipe screen with the use of empirical data. As shown in the technical information provided within the publicly available CASQA trash full capture approval documents, the orifice equation method has since been engaged across the industry for use in CPS's and catch basin inserts in California.

The orifice equation uses a simplified version of the Bernoulli equation, which defines horizontal flow for an incompressible fluid in ideal conditions. The simplifications assume that the orifice discharges into the atmosphere (i.e., free discharge conditions), the orifice is small compared to the reservoir (e.g., single outlet to a tank), and that the height difference is negligible where the elevation changes across the orifice. The orifice equation uses the area of the orifice and a coefficient of discharge (C_d) to account for the non-ideal flow conditions in practical applications, such as turbulence or occlusions. The orifice equation can be applied to flow through screens as follows:

Eq. 1 $$Q_F = \left(C_d A_f \sqrt{2gh}\right)/S\,F$$

Where Q_F is the filtered flow capacity, C_d is the coefficient of discharge, A_f is the screen open area, g is gravitational acceleration, h is the filter's driving head and SF is the safety factor.
The coefficient of discharge, C_d, is a unitless number that is defined by the actual flow (Q_{actual}) over theoretical flow ($Q_{theoretical}$). The actual flow, Q_{actual}, is an empirical measurement and the theoretical flow, $Q_{theoretical}$, is defined by the Bernoulli equation or other ideal flow assumptions.

The C_d is usually between 0.6 and 0.9 for a single orifice, which is likely the reason a C_d of 0.6-0.62 has been adopted in the industry. The C_d used in the LA County Public Works report was 0.53, as empirically derived through field testing of the CPS at that site and for that screen geometry, as shown in Figure 7.

Figure 7 Images from the County of Los Angeles Department of Public Works Technical Report entitled Connector Pipe Screen Full Capture TMDL Compliance Screen and bypass sizing requirements (Moon, 2007).

Application

The LA County Public Works method, or single orifice equation approach, can be illustrated as shown in Figure 8 when applied to a catch basin insert trash capture device.

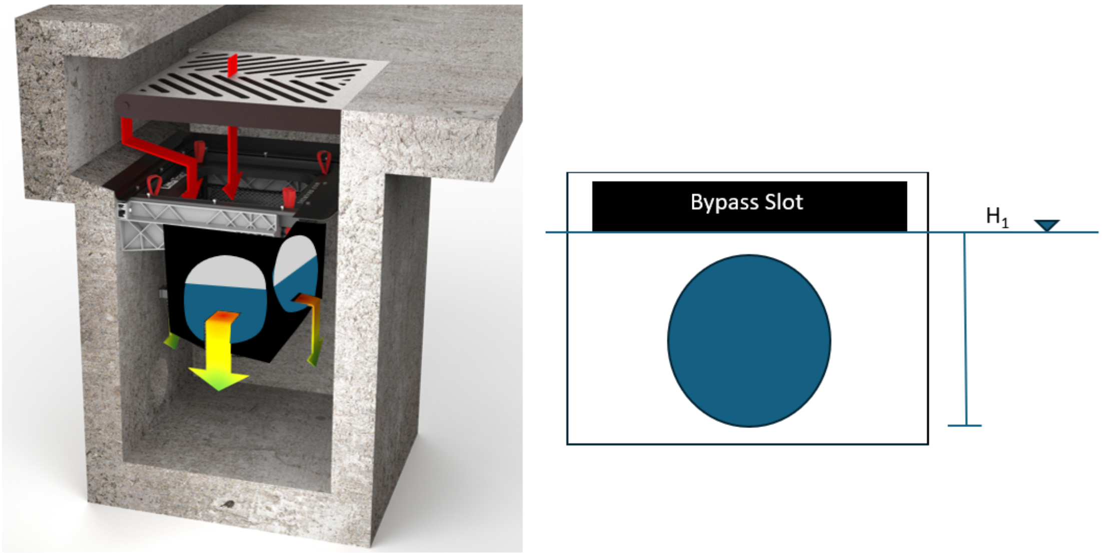


Figure 8 Illustration to demonstrate the single orifice method of calculation in the context of a catch basin insert where a single orifice is assumed for each side of the catch basin insert.

The LA county single orifice equation was used to calculate the maximum volume of flow that can be passed through the 4.8mm stainless steel screen in free discharge conditions using each:

- the industry-adopted coefficient (C_d) of 0.61,
- the empirically tested coefficient (C_e) of 0.41.

The purpose is to compare these calculated results with the laboratory testing, integrated orifice and driving head method, and the CFD for the screen in free discharge conditions.

The single orifice method was also applied to calculate:

- the maximum treatment flow rate for a stainless-steel basket 24” x 24” catch basin insert in free discharge conditions when 50% full using:
  - the industry-adopted C_d of 0.61
  - the empirically tested C_e of, 0.41.
- the change in water surface elevation across the screen in flume as a measure of screen resistance in tailwater conditions using:
  - the industry-adopted C_d of 0.61
  - the empirically tested C_e of, 0.38.

All results are tabulated and presented with results from the remaining methods in the Results section of this report.

Integrated Orifice and Driving Head Calculation Method

Description

This method uses a combination of the orifice equation and the driving head. The orifice equation is applied to each individual orifice, rather than assuming a single orifice as described under the previous method, and the driving head for each row of orifices is considered, as illustrated in Figure 9.

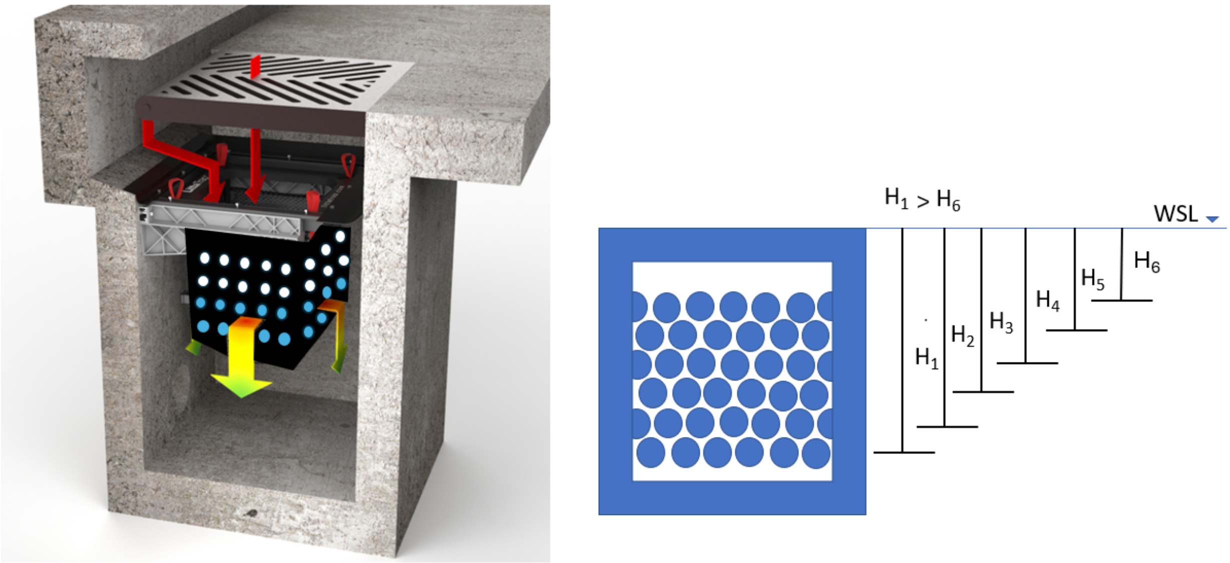


Figure 9 Illustration to demonstrate the integrated orifice and driving head calculation method where each row of individual orifices has an individual driving head.

In this method, the flow rate for each individual orifice per row for the length of material at depth H is calculated and added together. The flow per orifice in the bottom row, with H_1. is greater than the flow per orifice in row H_6 as a function of the driving head (Figure 9). Therefore, the flow rate for each row of orifices reduces with elevation thus reducing the flow calculated overall when compared to the single orifice method. In addition, the ratio of the hole circumference to the hole area (wetted perimeter) is correct whereas the single orifice method is not. A coefficient of discharge of 0.60 is appropriate in free discharge conditions because each individual hole is a sharp-edged single orifice.

Application

The integrated orifice equation and driving head method was used to calculate the volume of flow that can be passed through the 4.8mm stainless steel screen in the flume using a coefficient of discharge of 0.60 for each orifice in free discharge and in tailwater conditions. The purpose is to compare the results of this numerical model with the laboratory testing, the single orifice method, and the CFD.

The integrated orifice and driving head method was also applied to the 50% full 24" x 24" stainless steel basket catch basin insert scenario using the same coefficient of discharge 0.60. The full-scale CPS scenario was not calculated using this method given complexities introduced by the geometry of the screen and the outlet pipe.

All results are tabulated and compared with the remaining methods in the Results section.

Stage-Discharge Empirical Laboratory Testing and Calculation Method

Description

The stage-discharge method involves a relationship between two parameters: stage (depth of water) and discharge (flow rate, Q) (Figure 10). The stage and discharge relationship for both free discharge and tailwater conditions were measured to derive the specific flow rate for the 4.8mm stainless steel with 51% open area. Like the coefficient of discharge, this is a measure of the hydraulic efficiency of the 4.8mm stainless steel. This is not a dimensionless ratio, however, it is an actual measurement of the water surface elevation for a given flow rate which is then used to determine the coefficient of discharge for each of the conditions (free discharge and tailwater).

The specific flow rate calculation breaks down the flow and area of the submerged screen area to provide a flow rate for the material in terms of l/sec/cm. This can then be applied to the perimeter of a given geometry. Similar to the integrated orifice and driving head calculation method, this method considers the effects of driving head in the water column at each stage hence there is a decrease in flow rate per cm of elevation.

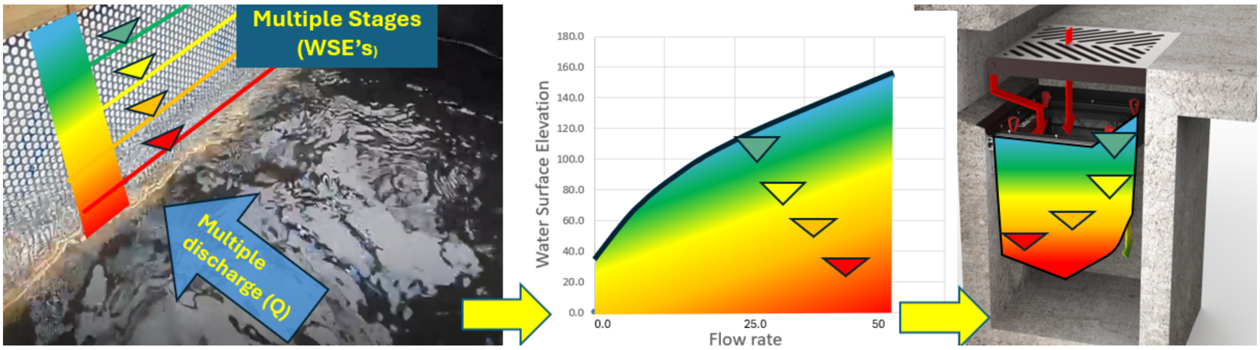


Figure 10 Illustration to demonstrate the stage-discharge method of calculation. Flow is fastest at the bottom of the column (red) due to the weight of water above it acting as the driving head in free discharge conditions.

Application

The stage-discharge method was used to calculate the maximum flow that can be passed through the 4.8mm stainless steel screen. The laboratory testing was also used to derive the coefficient of discharge for the 4.8mm stainless steel screen in both free discharge and tailwater conditions.

The purpose is to compare the empirical data with the single orifice method, the integrated orifice and the driving head method and to validate the CFD in free discharge conditions. The change in water surface elevation across the screen was measured for tailwater conditions to compare with calculations and the CFD.

The data from the stage-discharge relationship were also applied to calculate the treatable flow rate for a 24" x 24" stainless steel basket catch basin insert when 50% full. The full-scale CPS scenario was not calculated using this method given complexities introduced by the geometry of the screen and the outlet pipes relative tailwater impacts.

All results are tabulated and compared with the remaining methods in the Results section.

Computational Fluid Dynamics

Description

Computational fluid dynamics uses a supercomputer to calculate the flow in each model. The computer models hydraulic interactions in a three-dimensional space based on velocity and velocity squared, and measures of pressure and resistance. Assumptions made within the model include a water density of 1000 kg/m^3, water viscosity of 8.8871E-4 Pa-s, and gravity of 9.81 m/s^2. CFD can consider the complexities of the interaction catch basin insert and the catch basin geometry and can be considered a more accurate and holistic approach than the simplified math used in previous methods.

Applications

Laboratory

The laboratory testing flume and screen measurements were input into a CFD model. The CFD model was then run for the same scenarios that were carried out in the laboratory (Figure 11 and Figure 12). The free discharge and tail water scenarios with the screen in the flume were completed to allow comparison of results with the single orifice method, the integrated orifice and the driving head method, and stage-discharge method. The stage-discharge data validates the CFD model in turn i.e., real testing vs. simulated if the data agree.

Basket catch basin inserts

The basket catch basin insert of Figure 2 was modeled in a 24"x 24" catch basin with an 18" (450mm outlet pipe) and the connector pipe screen of Figure 6 was modeled in a 7-foot curb inlet catch basin also with an 18" (450mm) outlet pipe. These models allow a comparison of the CFD calculations versus the simplified math of the other methods.

The complex interactions of the basket catch basin insert with the catch basin shown in Figure 13 demonstrates how the CFD model can consider the insert as part of the overall system. It is interesting to observe the restrictions imposed by the basket and the outlet pipe and how this influences the overall capacity of the system, which the simplified models cannot consider. The results of the CFD scenarios are tabulated in the results section alongside all other results.

Basket Bypass Modelling

Bypass modeling is included to exemplify the complexities of basket bypass interactions with catch basin walls. The CFD model is bypass for a double basket insert geometry, which is different to that already explored in this study, however, the complexities beyond the single orifice calculation method when applied to basket inserts are still applicable. The single orifice equation is considered appropriate for bypass flows given that a bypass is a single rectangular orifice or similar. The results are provided in the Results section of this report.

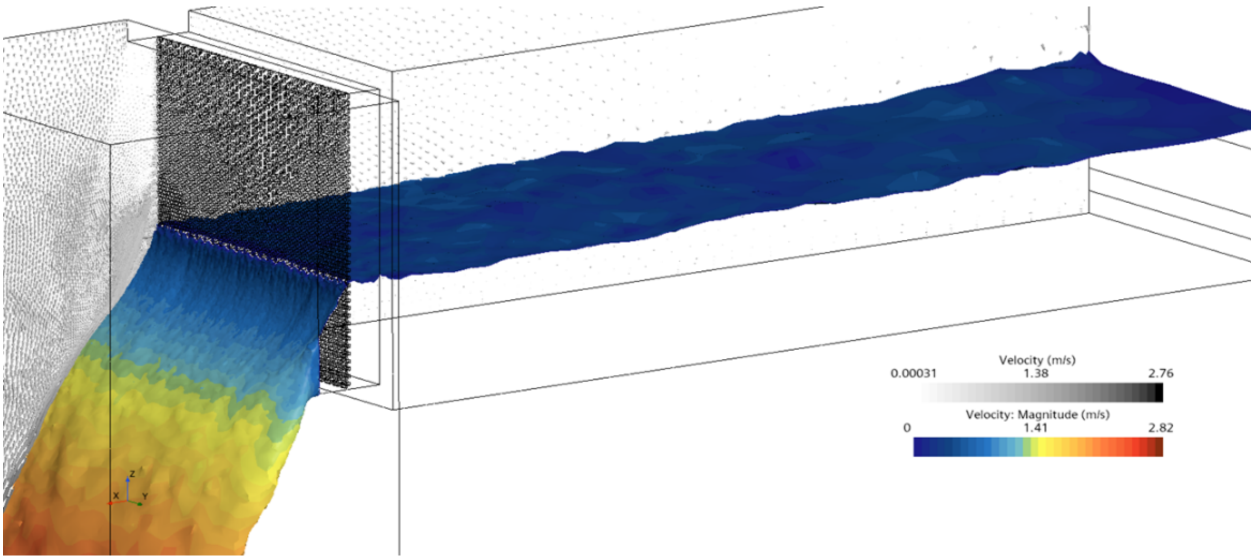


Figure 11 CFD Simulation of the laboratory flume and stainless-steel screen in free discharge conditions

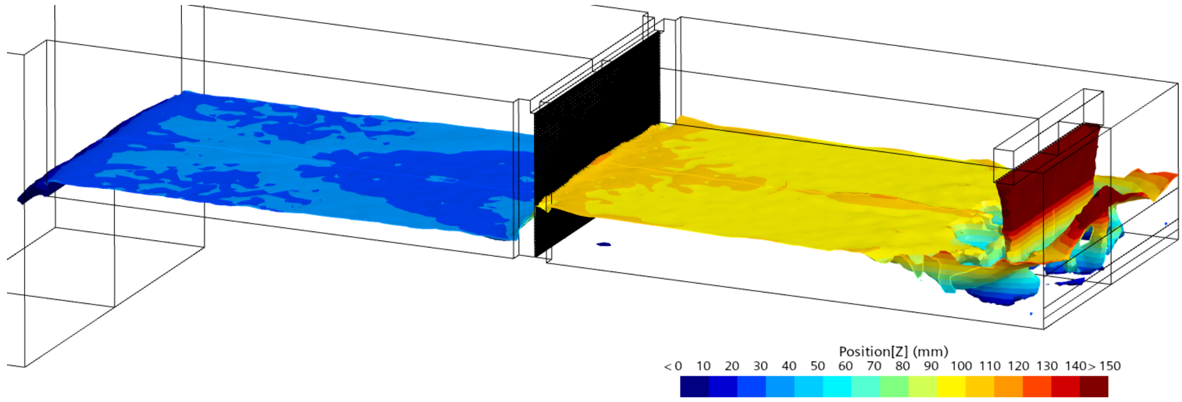


Figure 12 CFD Simulation of the laboratory flume and stainless-steel screen in tail water conditions.

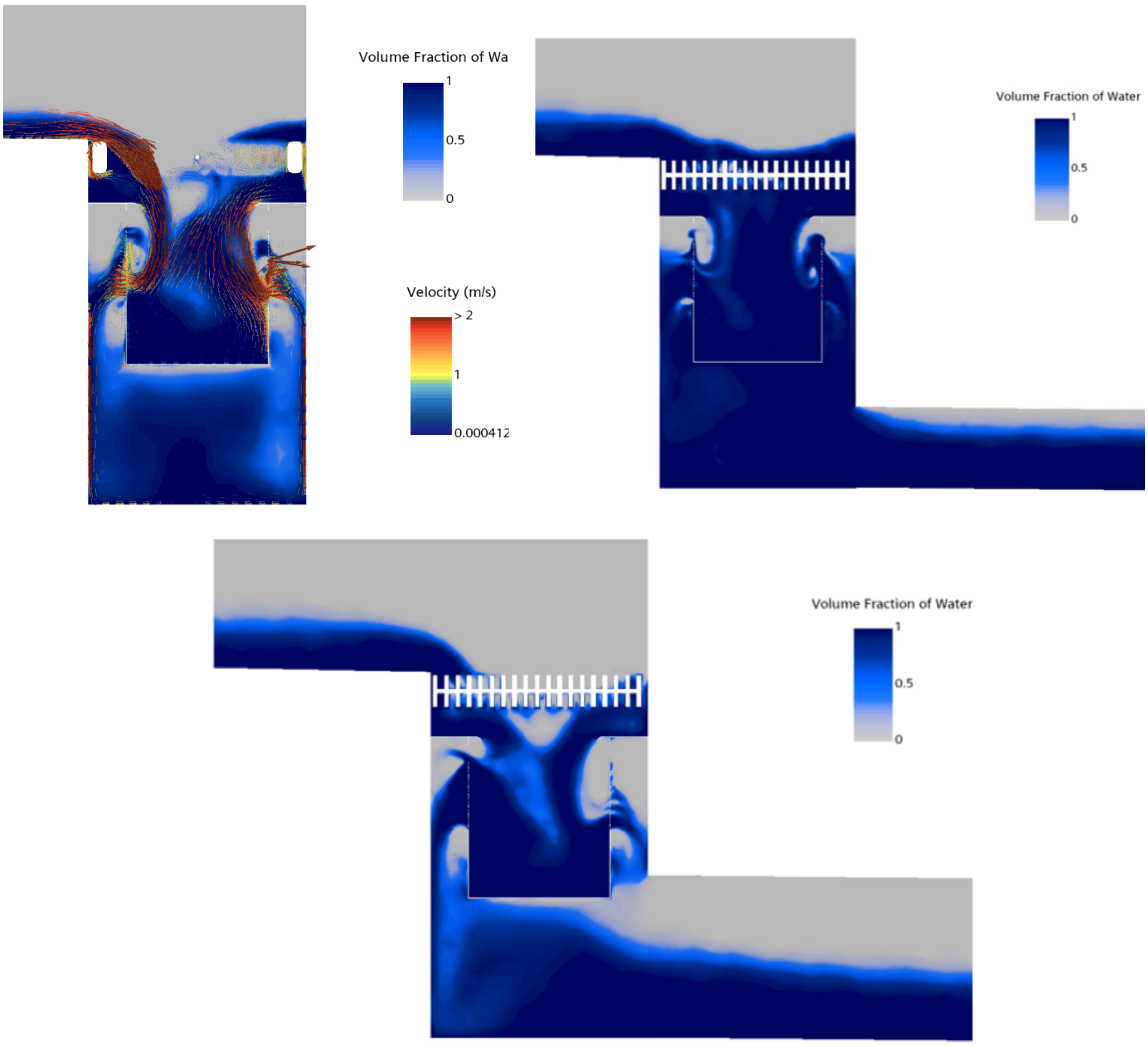


Figure 13 (Top Left) CFD showing Interaction with catch basin geometry at 50% MCTV; (Top Right) Example of the full CFD model showing surface water flowing into a standard 24 x 24 catch basin with a 10" outlet pipe and a typical Caltrans bolted slat design grate with 3/4 "opening and ½" slats for a design flow rate of 107.6 L/s and 50% MCTV. (Bottom) Example of the full model showing surface water flowing into a standard 24 x 24 catch basin with an 18 inch outlet pipe and a typical Caltrans bolted slat design grate with 3/4 "opening and ½" slats for a design flow rate of 107.6 L/s and 50% MCTV

Full Scale Connector Pipe Screen

Geometry and Design Flows

An 18" (450mm) connector pipe screen within a 7 ft catch basin with dimensions provided in Table 1 and Figure 6 was considered for this exercise. The geometry and design flows are as recommended in the LA County Report (Moon, 2007) and the screen material remains as stainless steel with 4.8mm holes and 51% open area as for the remainder of this study.

Table 1 Catch basin and screen geometry with recommend values. Taken and adapted from Moon (2007).

Catch basin Depth	Catch basin width	Max Q_{10}	Bypass height	Freeboard	Screen height	Clearance	Screen length	Screen Capacity
1.05m (3.5')	2.13 m (7')	150 LPS (5.3 CFS)	150mm (6")	150mm (6")	450mm (18")	250mm (10")	900mm (2.9')	82.1 LPS (2.9 CFS)

The purpose of this exercise is to determine the depth of tailwater acting on the screen within the full geometry of a catch basin with outlet pipe as opposed to the 'screen in flume' scenario using the three methods. Furthermore, the exercise is intended to exemplify the importance of considering the effect of tail water acting on a screen, which appears to have been lost in some of the recent connector pipe screen designs that apply the 2007 LA County Technical Report methodology.

Tailwater Depth Hand Calculation Methods

LA County Critical Depth

To determine the tailwater depth downstream of the connector pipe screen in a catch basin with dimensions of 7 feet in width and 3.5 feet in depth, Equation 3 and Equation 4 of the LA County Connector Pipe Screen Technical Report (Moon, 2007). These equations are applied as part of the LA County critical depth method for analyzing flow at the design flow rates of 2.9 CFS (82.1 LPS) and 5.3 CFS (150 LPS). Equation 3 of the LA County Report is the orifice equation already discussed (Eq. 1) and Equation 4 of that report is defined as follows:

Eq.2 $$D_d = \mathrm{d}_C + 1 \cdot 2\frac{v^2}{2g}$$

Where D_d = downstream depth, d_C = Critical depth, representing the minimum depth at which flow is stable in a supercritical state, V = velocity of flow through the connector pipe screen, g = Acceleration due to gravity and the factor, 1.2, is an empirically derived multiplier that represents entrance losses specific to the conditions defined in the LA County Hydraulic Design Manual.

This equation helps establish the downstream depth, factoring in critical depth and outlet losses, which are essential for predicting flow behavior under supercritical conditions in steeply sloped pipes.

CPPA Design Manual Culvert Inlet

To determine the tailwater depth using the CPPA Design Manual (2012), the outlet pipe of the catch basin was assumed to be a culvert inlet. Assumptions included that the outlet pipe was a culvert under inlet control, not flowing full and with a square-edged headwall. These assumptions in conjunction with pipe diameter and design flows enabled use of the 'headwater depth for concrete pipe culverts with inlet control' chart (Figure 3.3 of the CPPA Manual).

Computational fluid dynamics

The CFD modelled in a 7 ft curb inlet catch basin with an 18" (450mm) outlet pipe inclined at 0.10 m/m (5.71°) as shown in Figure 6 and Table 1.

The following scenarios were run through the CFD model:

- $Q_{1\text{-}10}$ = 2.9 CFS (82.1 LPS) with full-screen capacity
    - The 82.1 LPS was allowed to pass through the full height of the screen.
        - The purpose of this run was to determine a baseline tailwater depth at the outlet pipe for the screen and outlet pipe geometry.
- $Q_{1\text{-}10}$ = 2.9 CFS (82.1 LPS) with 50% screen capacity
    - This run was carried out with the same assumptions as per the LA County report, therefore the bottom 50% of the screen was blocked out.
    - The purpose of this run is to
        - Exemplify how the coefficient of discharge and screen orifice geometry affects the capacity of the screen when compared to the recommended values provided in the LA County report.
        - Determine the depth of tailwater at the outlet pipe.
- $Q_{CB\text{-}MAX}$ = 5.3 CFS (150 LPS) with the full screen blocked (0% capacity)
    - This is the maximum 10-year event recommended for the catch basin geometry as provided in the LA County Report (Moon, 2007)
    - The purpose of this run is to determine the bypass capacity

Examples of the CFD model output and how the tailwater depths were measured are provided in Figure 15 and Figure 15.

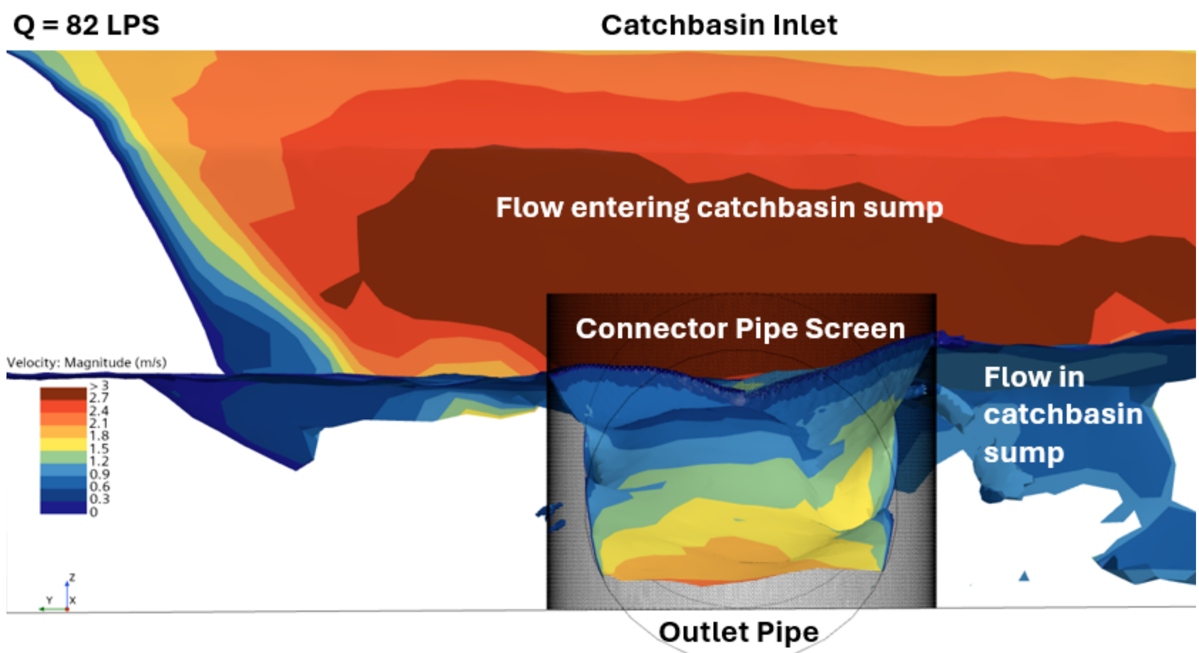


Figure 14 Example of CFD model velocity profile looking into the catch basin from the outlet pipe

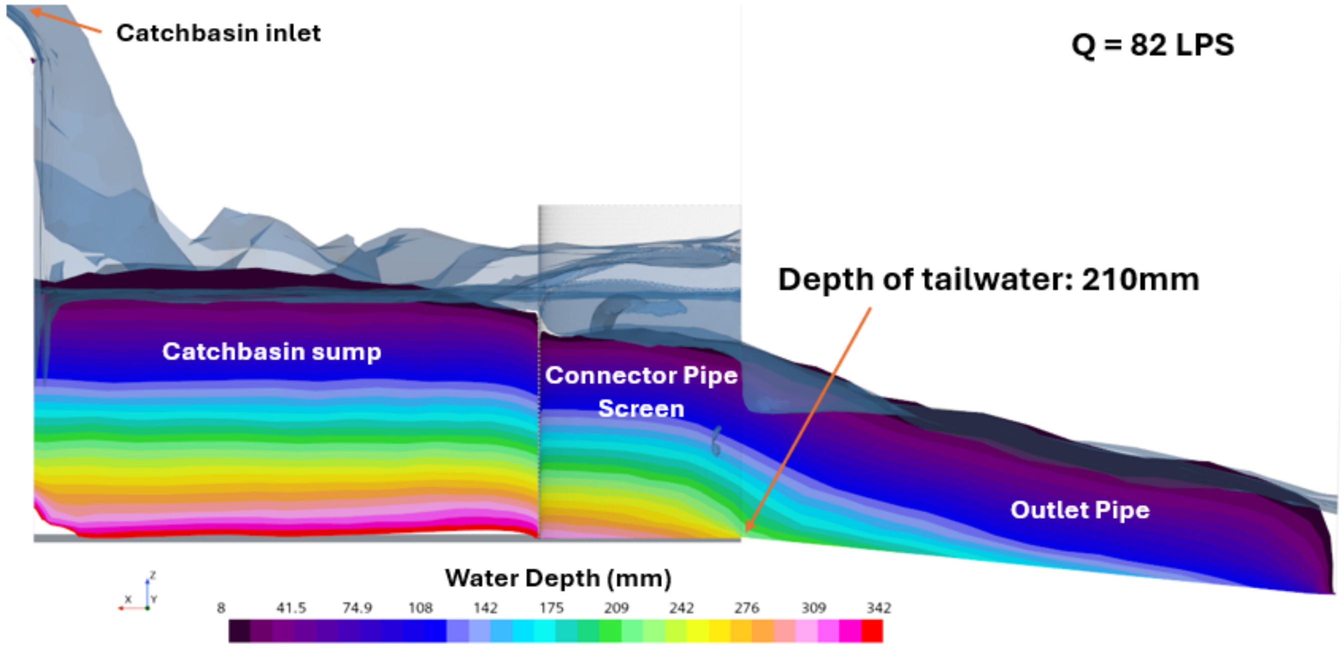


Figure 15 Cross-sectional view of CFD to show depth profile from the to the outlet pipe.

Results

Free Discharge Flume Screen Comparison

The results provided here are for the free discharge laboratory configuration shown in Figure 3 and Figure 11. Table 2 and Figure 16 provide the results for the maximum flow (Q_{max}) that can be passed through the screen shown in Figure 2. The single orifice method and integrated orifice and driving head methods use a theoretical calculation that includes a coefficient of discharge (C_x). The C_d of 0.61 is the assumed coefficient of discharge adopted for screens in the industry, and the coefficient of discharge, C_e 0.41, is empirically derived in the lab for this material.

All methods agree well except for the LA county method with the assumed C_d of 0.61. This calculation suggests that the screen capacity is 33% greater when compared to other methods.

Table 2 Tabulated results for the free discharge screen in the flume

Method	C_x	Q_{max} (CFS)	Q_{max} (LPS)
Single Orifice (C_d)	**0.61 screen *assumed***	**2.93**	**83**
Single Orifice (C_e)	0.41 screen *empirical*	1.97	56
Integrated orifice and driving head	0.60 per individual orifice	1.94	55
Stage discharge (Lab)	n/a	1.94	55
CFD	n/a	1.97	56

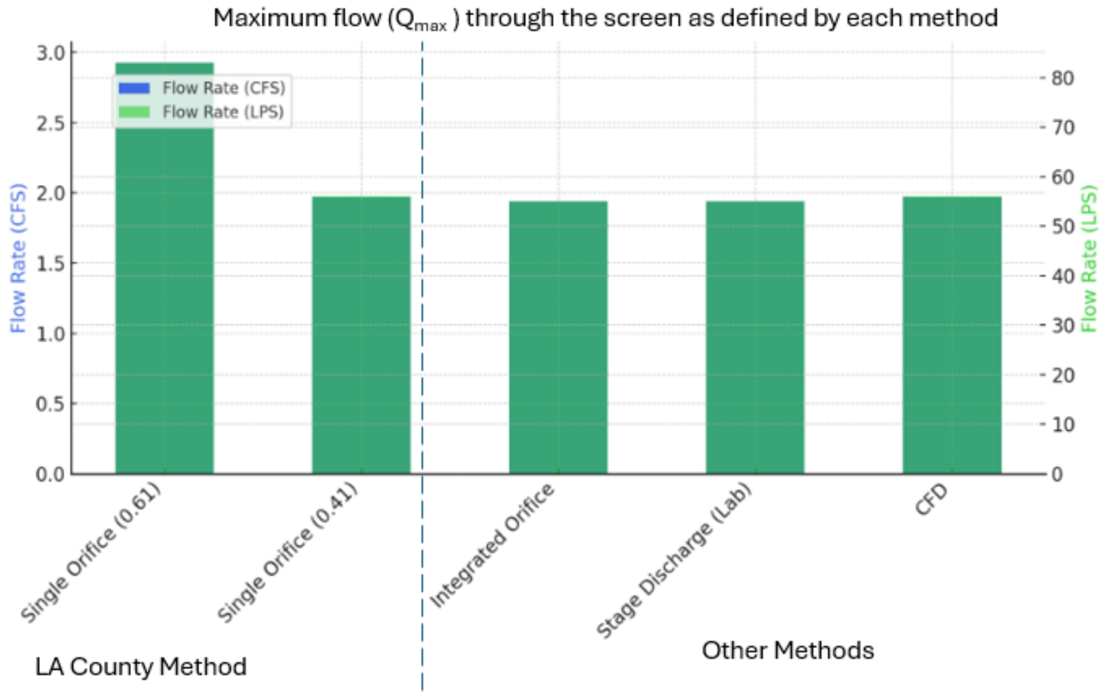


Figure 16 Graphical representation of results provided in Table 2. Note that all methods agree well except for the single orifice LA County Method when the assumed coefficient (C_d) of 0.61 is used.

Applied Free Discharge: 24" x 24" Catch Basin Basket Insert Comparison

This section provides results for the maximum treatment flow rate calculated for a stainless-steel basket in a 24"x 24" catch basin with 51% open area and 4.8mm holes at 50% Maximum Trash Capture Volume (MTCV). The basket, shown in Figure 4, is assumed 7.8" (0.2m) below ground level and there is no factor of safety included in these calculations. Table 3 and Figure 17 provide tabulated and graphical results. All bypass flow calculations use the orifice equation and a bypass coefficient, C_b, of 0.61, which is considered appropriate for a single sharp-edge steel orifice at the bypass.

For the screen, the C_d of 0.61 is the assumed coefficient of discharge adopted in industry and the C_e of 0.41 is the value empirically derived for the stainless steel with 4.8mm holes and 51% open area shown in Figure 2.

The results show a bigger difference between the LA County single orifice method and the other three methods than for the screen only. It appears that the overestimate in the orifice equation is amplified when applied to a basket regardless of the coefficient applied (0.61 vs 0.41).

Table 3 Tabulated results for the applied free discharge basket catch basin insert scenario.

Method	C_x	Peak Flow Rate (50% MTCV)		Bypass with C_b	
		CFS	LPS	CFS	LPS
Single Orifice (C_d)	**0.61 basket assumed**	**14.09**	**399.02**	3.47	98.25
Single Orifice (C_e)	**0.41 basket empirical**	**9.47**	**269.19**	3.47	98.25
Integrated orifice and driving head	0.60 per individual orifice	6.0	169.93	3.47	98.25
Stage discharge	n/a	7.61	215.4	3.47	98.25
CFD – 18" outlet pipe	n/a	6.08	172.16	n/a	n/a

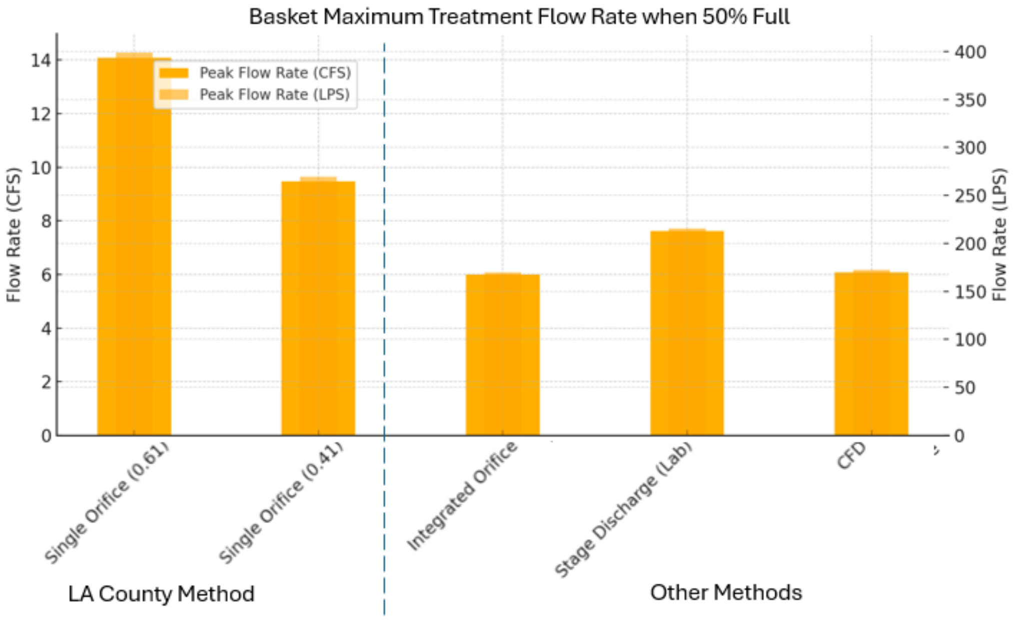


Figure 17 Graphical representation of results provided in Table 3. Note that the LA County Method with the assumed coefficient (C_d) of 0.61 is more than double the integrated orifice and CFD approaches.

Catch Basin Insert Bypass Model

The calculated bypass capacity is 9 CFS (256 LPS) for the configuration shown in Figure 18. The dashed red line indicates the surface flooding level, which is observed at 5.3 CFS (150 LPS). The CFD model shows that interaction with the catch basin walls, and adjacent basket creates an air pocket resulting in a significant reduction of the bypass capacity and therefore reducing flows by over 40% from the calculated bypass capacity. The results of the CFD scenarios are tabulated in the results section alongside all other results. Restrictions in the system outside of the baskets cause surface flooding to occur at 5.3 CFS (150 LPS) where the calculated flow rate for that scenario is 9 CFS (256 LPS).

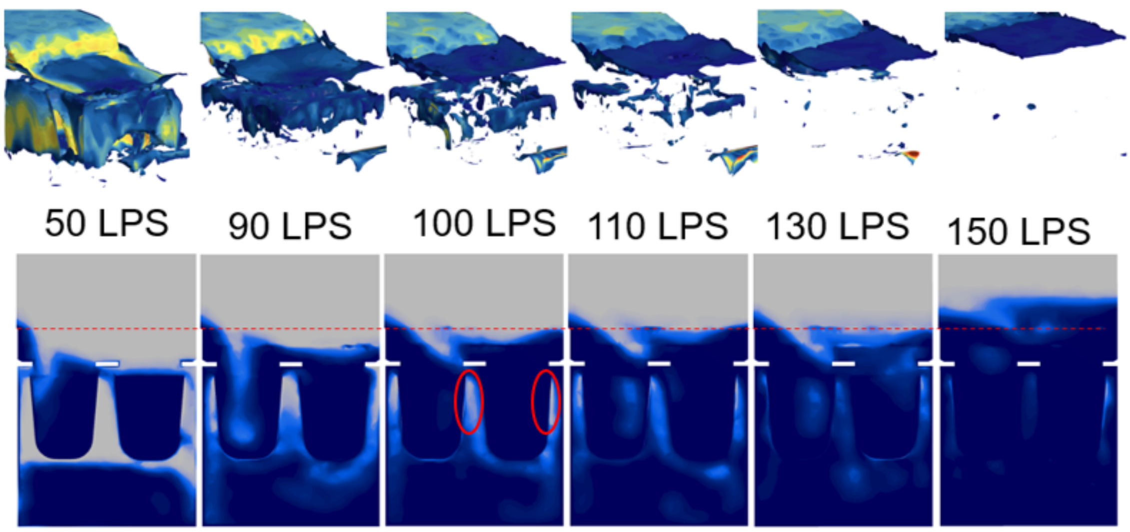


Figure 18 Example double basket scenario with a calculated bypass of 9 CFS (250 LPS). Note the light blue on either side of each basket (shown in red at 100 LPS), which shows an airlock and space that cannot be used and the red dashed line, which indicates surface-level flooding. This exemplifies the complexity and bypass interaction with the catch basin walls.

Tailwater Flume Screen Comparison

Each method was used to calculate the difference in water surface elevation (ΔWSE) across the screen for the geometry shown in Figure 5. The solution for this case is iterative because the tailwater at each flow rate affects the driving head. Therefore, the maximum flow rate that can be passed through the screen, 1.94 CFS (55 LPS) as identified in the free discharge calculations, was used to compare the results. Like the free discharge results, the integrated, stage discharge and CFD approaches yield similar results to each other. However, in the tailwater scenario, the LA County methodology suggests the screen is too efficient when the C_d 0.61 is used and too restrictive when the empirically derived C_e 0.38 is used.

Table 4 Tabulated results for the difference in water surface elevation across the screen in flume tailwater conditions in the

Method	C_x	ΔWSE (mm)
Single Orifice (LA County, C_d)	**0.61 (screen assumed)**	**92**
Single Orifice (LA County, C_e)	0.38 (screen from lab data)	238
Integrated orifice and driving head	0.6 (per orifice)	140
Stage discharge	n/a	172
CFD	n/a	172

Figure 19 Graphical representation of results provided in Table 4. Note that the LA County Method with the assumed C_d of 0.61 suggests the screen is much more efficient than the LA County single orifice method laboratory-derived C_e of 0.38. The other three methods agree fairly well when compared to the differences within the LA county method.

Connector Pipe Screen

Full Size Screen Tailwater Depth Calculations

The full catch basin and connector pipe screen geometry were analyzed using CFD, the LA County critical depth method and a culvert inlet design to determine the depth of tail water expected to be at the inlet of the outlet pipe. Results for the methods are provided in Table 5 and Figure 20. The culvert inlet design manual and the CFD tailwater levels agree well for 2.9 CFS (82 LPS). The hand calculation is approximately 15mm more conservative than the CFD. This could potentially be attributed to the accuracy of the CFD model when compared to assumptions made when completing the design based on the manual. CFD was not completed for the 5.3 CFS design flow.

Table 5 Tailwater depth downstream of CPS as calculated by each method

Method	Screen Condition	Flow rate (CFS)	Flow rate (LPS)	Water level at the outlet pipe (mm)
CFD	Full screen	2.9	82.1	261
	50% blocked	2.9	82.1	300
	100% blocked (bypass)	5.3	150.0	~1000
CPPA Design Manual	N/a - Independent of screen	2.9	82.1	274.5
		5.3	150.0	423
LA County Method	Full Screen	2.9	82.1	171
	Full Screen	5.3	150.0	261
	50% blocked	2.9	82.1	179
	50% blocked	5.3	150.0	354

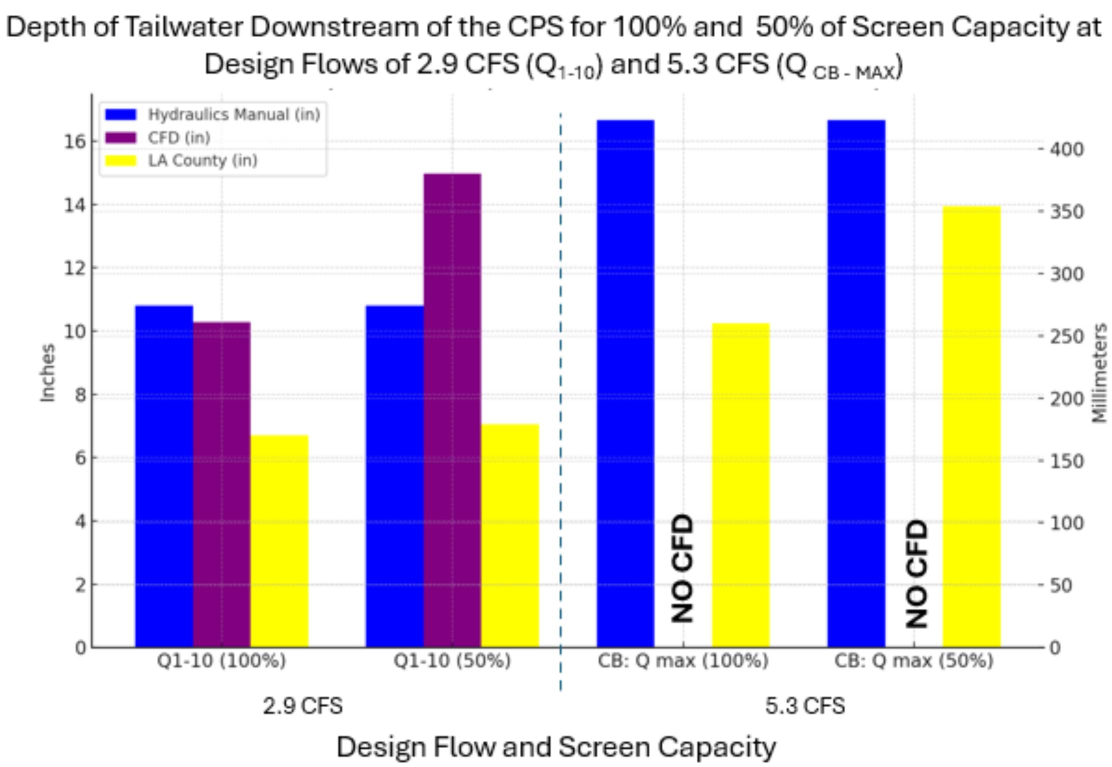


Figure 20 Graphical representation of results provided in Table 5.

Connector Pipe Screen Bypass Capacity

The orifice equation calculated the bypass capacity of the CPS as 6.14 CFS (173 LPS).

A bypass capacity check with the CPS 100% blocked in the CFD model shows the catch basin near flooding when conveying 5.3 CFS (150 LPS). It appears there is a pocket of air reducing the bypass capacity in the CFD model when compared to the orifice equation, like that seen in the double basket scenario shown in Figure 18.

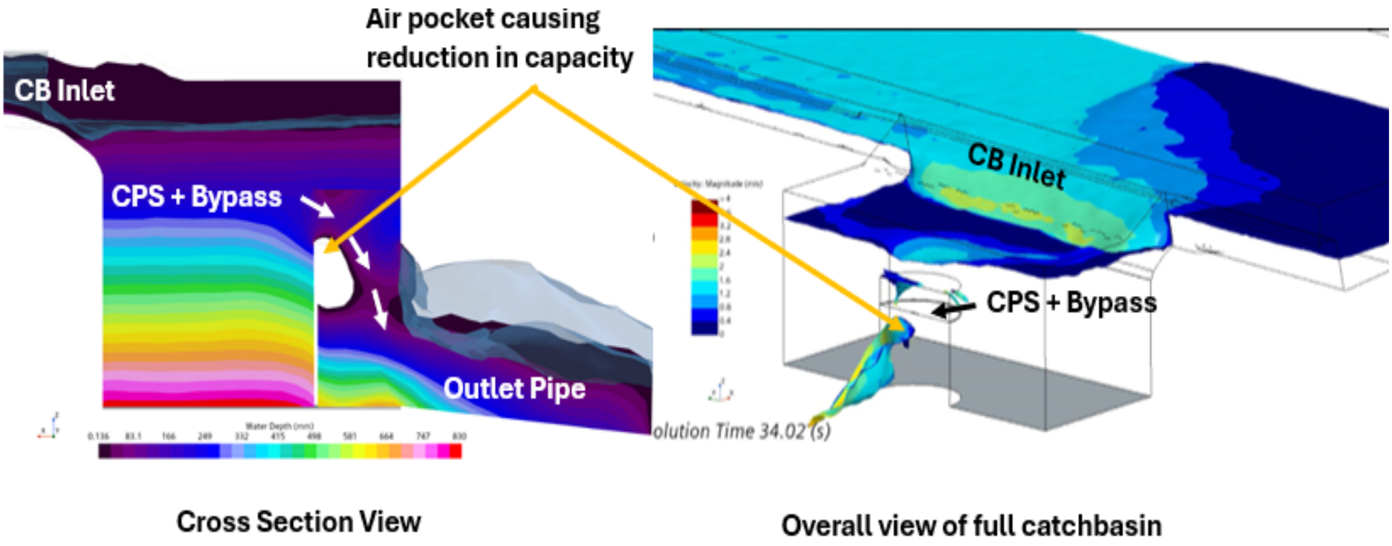


Figure 21 Illustration of CFD to show where an air pocket is likely reducing the bypass capacity of the CPS when modeled as 100% with the maximum catch basin design flow, 5.3 CFS (150 LPS).

Discussion and conclusions

Discussion

The LA County Report states that the screen coefficient, C, is unique to each orifice geometry and that orifice conditions for screen holes differ substantially from the conditions used to determine standard orifice coefficients (Moon, 2007). Therefore, the C_d is empirically derived for the connector pipe screen in that report. The field testing yielded a C_d of 0.53, which was the lowest value from five test runs at their facility. The C_d varied during testing due to occlusions on the screen because even the slightest change in area can drastically impact the screen's coefficient. The lowest value, 0.53, was taken to ensure a conservative approach was adopted for that work (Moon, 2007).

Since then, the industry appears to have adopted the single orifice method for use in catch basin inserts. Catch basin inserts differ from the LA County research, which was carried out for connector pipe screens. A connector pipe screen operates in tail water conditions and a catch basin insert operates in free discharge conditions. Moreover, the single orifice method has been widely adopted with the use of a screen coefficient or C_d of 0.61, which is described in literature as appropriate for a single sharp-edged orifice. A trash screen is not a single sharp-edged orifice regardless of tailwater or free discharge conditions. Laboratory testing in this study found that a C_d of 0.61 was unachievable for the stainless-steel screen with 4.8mm holes and 51% open area. The C_e obtained for the screen in free discharge conditions was 0.41 and for tailwater conditions was 0.38.

Free discharge

The LA County single orifice calculation method was applied to the free discharge 'screen in flume' scenario to find the maximum flow that can be passed through the screen illustrated in Figure 2. Using the industry assumed C_d value of 0.61 the maximum flow rate that can be passed through the screen in free discharge conditions was approximately 3.0 CFS (85 LPS). When the assumed coefficient is replaced with the empirically derived coefficient (0.41), the maximum flow rate is approximately 30% less.

The remaining results agree with the single orifice calculation when the empirically derived screen coefficient, C_e 0.41, is used for the free discharge screen in the flume scenario (Table 2). The integrated driving head and orifice method, stage-discharge and CFD method all yielded just under 2 CFS (57 LPS). These results show that applying the assumed discharge coefficient, 0.61, and the single orifice method as done in the LA County Technical Report is not appropriate. A C_d of 0.6, however, is appropriate in the context of the integrated driving head and orifice method where each single orifice is being considered.

The applied 24"x 24" stainless steel basket calculation provided results with a similar pattern. The single orifice method results were much higher than the remaining methods. In the applied 24" x 24" basket scenario, the single orifice method with a C_d of 0.61 calculated the basket peak flow rate to be approximately 14.0 CFS (396 LPS). Again, this result is approximately 30% higher than where the empirically derived coefficient is used and almost 60% higher than the integrated and CFD methods. These results support that the single orifice method with an assumed C_d of 0.61 is inappropriate for catch basin inserts.

Considering Figure 8 and Figure 9 it is somewhat obvious how such a difference in results may occur when applied to a catch basin insert. The data also support that the coefficient of discharge will differ for each test and material geometry meaning that the widely adopted single orifice method with a C_d of 0.61 can overestimate the hydraulic capacity if used out of context. As stated by Moon (2007) the C_d for trash screening devices should be empirically determined for specific geometries, materials, and flow conditions. The onus should be on the supplier to ensure an appropriate coefficient is derived for their product and regulators should have the knowledge to approve or disapprove appropriate testing and parameters.

Another aspect of the CFD modelling is that the overall hydraulics of a system affect the performance of the basket insert bypass capacity. The modelling shows that although the calculated bypass flows for a double basket catch basin insert are calculated to be 9 CFS (256 LPS), the interaction with the catch basin created air pockets that cannot be utilized by the flow during a storm. These air pockets significantly reduced the bypass from 9 CFS (256 LPS) to 5.2 CFS (150 LPS) where surface flooding is suggested to occur in the model. This model shows that the bypass capacity is not just dependent on the opening but also the overall system hydraulics and catch basin geometry.

Tailwater

The study's analysis of tailwater conditions highlights significant discrepancies in hydraulic performance when applying different calculation methods to trash screen devices. Tailwater conditions, where the water level downstream of the screen affects the flow dynamics, present unique challenges in predicting accurate flow rates. Each method— the single orifice method, integrated orifice and driving head method, stage-discharge empirical testing, and computational fluid dynamics (CFD) modeling—was used to estimate the change in water surface elevation (ΔWSE) across the screen under tailwater conditions within the laboratory flume.

The single orifice method, using the industry-standard discharge coefficient (C_d) of 0.61, significantly overestimated the screen's flow efficiency in tailwater conditions suggesting the screen was 50% more efficient than other methods. When compared with the empirical coefficient (C_e) of 0.38, derived from laboratory testing under tailwater conditions, the results suggest that the screen is 30% less efficient than the other three methods. These results clearly demonstrate how the standard C_d of 0.61 may lead to overly optimistic projections of screen capacity. If the laboratory-derived coefficient of discharge, 0.38, is used then the result is more conservative, which is favorable in terms of mitigating flood risk and accounting for screen occlusions.

The integrated orifice and driving head approach, stage-discharge empirical method, and CFD modeling showed greater consistency with each other and more accurately reflected the actual hydraulic behavior of the screen in the flume under tailwater conditions.

The connector pipe screen tail water depths in the CFD model agree well with the CPPA manual design for a culvert inlet when 100% of the screen capacity is available at 2.9 CFS (82.1 LPS). The LA Country critical depth method was approximately 40% less at 2.9 CFS but agreed fairly well for the catch basin's maximum flow rate, 5.3 CFS (150LPS) when the screen was 50% blocked.

The counterintuitive results show that the tailwater is deeper when the screen is 50% blocked as opposed to the scenario where 100% of the screen capacity is available for flow. The cause of this phenomenon is considered to be because when the screen is 50% blocked, the flow across the screen becomes free discharge from that point. There is already tailwater acting on the screen when 100% of the screen capacity is available, which reduces the efficiency of flow and therefore reduces the tailwater depth in that case.

Bypass

Bypass capacities were explored with CFD to compare with the orifice method. Unlike a screen with multiple holes, the orifice method is acceptable for bypass calculations given that the bypass slot is usually a single circular or rectangular orifice. The CFD models showed that because of interactions with surrounding geometries, the bypass capacities can be reduced by up to 40% due to air pockets. This highlights the importance of safety factors for bypass capacities.

Conclusion

As stated by the original LA County Technical Report of 2007, every screen needs to be tested to calculate the coefficient of discharge for that screen. The screen coefficient, C, is unique to each orifice geometry and orifice conditions for screen holes differ substantially from the conditions used to determine standard orifice coefficients (Moon, 2007). The testing and calculation approach needs to be simple and standardized to ensure consistency across the industry. Failing a standardized method across the industry each method should have a standardized safety factor, which is based on that method’s accuracy, to ensure equality across flow calculations regardless of the method used.

The stage-discharge method provided the most reliable result in all cases. It could be standardized for manufacturers to run a stage-discharge test on the material chosen for their catch basin insert given that the laboratory test would be required as the empirical test for the orifice equation regardless. The manufacturer can then develop a quadratic model specific to their material. This allows the calculation of flow per area as a function of the driving head that can be applied to any geometry. In addition, the bypass capacity can be significantly reduced by air pockets in some configurations. Bypass safety factors should be adjusted and standardized depending on the geometry and configuration of the catch basin insert and how it interacts with the catch basin.

Finally, the effects of tailwater on connector pipe screens are massive. There needs to be a simple standardized approach for calculating the depth and a safety factor should be applied. The culvert inlet design method is simple and does not require an iterative mathematical approach such as that required for the orifice and critical depth method. Again, the application of such a method would require a safety factor to ensure complexities introduced by the screen are accounted for.

Closing Remarks

CFD generated velocity plots for flow through a screen in tail water conditions versus free discharge conditions are provided in Figure 22. The flow velocity at the base of the screen in free discharge conditions is greater than further up the screen. This is explained by a greater driving head in the row of orifices at the base of the screen compared to those at the top of the screen the basis of the integrated orifice and driving head method of this study.

The velocity plot for tailwater conditions shows lower velocities due to the tailwater acting on the screen, which is an important consideration for connector pipe screens. The integrated orifice and driving head method was simple and accurate enough for a catch basin insert when the empirically derived coefficient of discharge was used. However, the integrated orifice and driving head method was not applied to the full geometry of the catch basin CPS and outlet pipe because of the complexities. Therefore, the use of simplified methods in the industry is warranted but when simplified methods, such as the single orifice method provided in the LA County report, are used the coefficient of discharge must be empirically defined for that device's material. The devices and their interaction with catch basin geometries involve complex hydraulics and a standard is required to regulate properly.

Tailwater Conditions **Free Discharge Conditions**

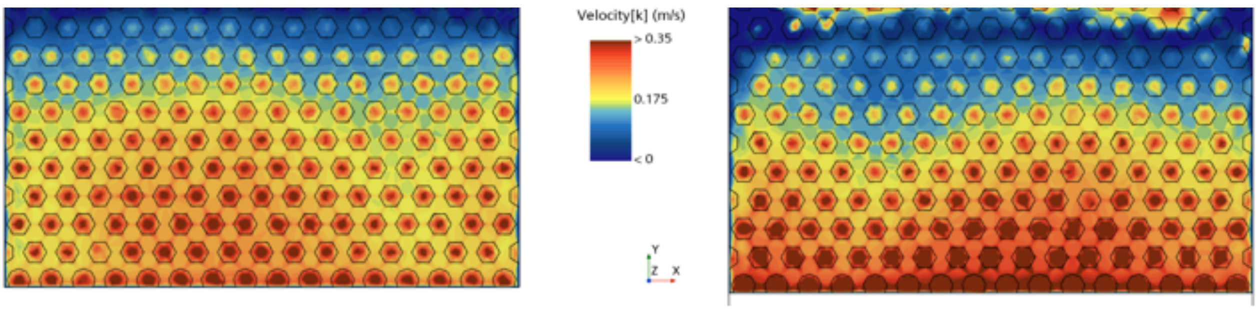


Figure 22 CFD generated velocity profile of the font of a screen when receiving flow in tailwater conditions (left) and free discharge conditions (right). The flow is approaching the screen from the back of the page and would be projected towards the reader.

Regulators should have a design standard that sets out requirements for hydraulic calculations and testing methodologies for new and retrofit devices to ensure designs are correct and consistent. The standard should include details on calculating the safety factor calculations and reporting values as 50% MTCV, for example. The ASTM trash testing standard (E 3332-23) is useful, but a standard for testing the hydraulic capacity of screens and the application of those results to various catch basin insert designs could be developed. For larger high-risk systems, perhaps the cost of CFD modeling is justified to better understand how the treatment flows and bypass will interact with the catch basin geometry. It should also be noted that flow through basket systems is cross flow which helps to sweep solids from the screen surface to reduce clogging whereas connector pipe screens are typically direct flow which pins solids to the screen surface and increase clogging. Clogging safety factors, which are considered separate from hydraulic safety factors, may also become an important consideration in the standardized design of these catch basin inserts.

Climate change is upon us. California's Fourth Climate Change Assessment (2018) report provides detailed regional projections and indicates that extreme precipitation could increase by approximately 20% to 25% for a 1-in-10-year storm event by 2050 in many parts of California.

More intense and prolonged rainfall events mean improved design standards are warranted to ensure flood prevention. If this threat is not addressed the implications of not meeting the TMDLs due to insufficient hydraulic treatment capacity and localized flooding due to inadequate bypass capacities could raise questions about liability for regulatory bodies and manufacturers. This study calls for a revaluation of design methodologies for trash screen devices and a set of guidelines for the design and testing of these products.

Future work

The outcomes of this work are intended to be part of ASTM trash testing protocol to ensure full trash capture at the same time as flood mitigation for climate change resilience.

The authors acknowledge further work is needed to develop a standard and that the impact of overestimating the flow capacity of catch basin inserts and pipe connector screens needs further exploration.

Future work will include a comparison of all the methods in this report in the context of full-scale hydraulic testing of a 24” x 24” catch basin insert and pipe connector screen and include full-scale hydraulic testing of bypass capacities with CFD validation. The full-scale connector pipe screen testing will include an analysis of tailwater impacts.

As noted above, a basket system uses cross flow to help sweep solids off the screen surface, reducing clogging. In contrast, connector pipe screens with direct flow tend to pin solids against the screen, increasing the risk of clogging. Therefore, further future research may need to consider clogging factors based on the flow direction relative to the screen, along with hydraulic safety factors that account for differences in geometry.

References

CPPA Manual. (2012). *HYDRAULICS OF PRECAST CONCRETE CONDUITS*. Retrieved from CPPA Technical Publications - Hydraulics: https://cpaa.asn.au/technical-publications/

Moon, T. S. (2007, April). *Technical Report: Connector Pipe Screen Design*. Retrieved from State Water Resources Control Board: https://www.waterboards.ca.gov/losangeles/water_issues/programs/tmdl/fcc/la%20county%20full%20capture%20request%20package.pdf

Ziaja, S. F. (2018). *California's Fourth Climate Change Assessment*. Retrieved from Statewide Summary Report: https://www.energy.ca.gov/sites/default/files/2019-11/Statewide_Reports-SUM-CCCA4-2018-013_Statewide_Summary_Report_ADA.pdf