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Publication details:
Report No. UNSW Water Research Laboratory Technical Report No. 2004/05

Publication Date:
2004

DOI:
https://doi.org/10.4225/53/58e188ebdd1b3

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TESTING OF ORIFICE SIZES
FOR SYORMWATER DETENTION SYSTEMS

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Technical Report 2004/05
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THE UNIVERSITY OF NEW SOUTH WALES
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
WATER RESEARCH LABORATORY

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Technical Report No	2004/05
Report Status	Final
Date of Issue	February 2004
WRL Project No.	04004
Project Manager	Steven Pells

Title	Testing of Orifice Sizes For Stormwater Detention Systems
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1. INTRODUCTION

The University of New South Wales, Water Research Laboratory (WRL) was commissioned by The Upper Parramatta River Catchment Trust (UPRCT) to test standard orifice plates under typical operating conditions.

UPRCT have been investigating the use of orifice plates to control discharge from on-site stormwater detention (OSD) systems and wished to know the minimum size (diameter) of orifice that would discharge to known discharge coefficients without blocking. UPRCT wished to investigate if there exists a critical orifice size under which blockage may occur by typical stormwater debris, despite being installed downstream of a screen.

UPRCT supplied to WRL seven (7) orifice plates (diameters 50 mm, 40 mm, 30 mm, 20 mm, 15 mm, 10 mm, 5 mm) and a standard Maxi-mesh RH3030 screen used to surround the orifice and protect it from blockage. WRL constructed a testing rig to measure discharge through each orifice plate under various head for both clear and debris laden water conditions. Results were used to determine the coefficient of discharge (C_D) for each orifice plate at different water levels.

This report describes the procedure used for testing the orifice plates and presents the test results.

2. TEST CONDITIONS

2.1 Test Rig

A schematic of the test rig is shown in Figure 1.

A square tank measuring 1.2 m by 1.2 m wide and 0.9 m deep was modified to allow internal mounting of the supplied orifice plates and the Maxi-mesh RH3030 screen. The orifice plates and mesh were mounted in a configuration similar to how they would be mounted when used in OSD systems (Figure 2). Mountings were set up so that the centreline of each orifice was 150 mm from the base of the tank. The Maxi-mesh screen was set up in its design position such that debris would be encouraged to fall from the mesh when not operating.

A flexible gasket was used to ensure that no water could leak around the back of the orifice plate and into the V-notch weir.

Water was supplied to the tank via rotameters of varying capacities (Figure 3). Flow baffles were used to ensure that water approaching the trash screen would be regular. A deflector (Figure 4) directed the orifice outflow into a V-notch weir. An electronic water level follower monitored water levels behind the V-notch weir to provide a measure of discharge (Figure 5).

A manometer tube was connected into the tank outside of the trash screen to measure water levels.

2.2 Instrumentation

The rotameters were not essential to the testing and were only used to simplify procedures. They aided in achieving tank-full steady state conditions and an appropriate rate of rise during the "rising head" tests (Section 3). Prior to testing, the rotameters were also used in a separate rig to verify the calibration of the V-notch weir.

The V-notch weir box featured a 28 degree "V" and the discharge formula is presented in equation 1.

$$Q = 374.39\,(H)^{2.5} \qquad (1)$$

where Q = discharge in litres per second

h = depth of water above weir in metres

The datum of the water level follower was set to the bottom of the V-notch weir. The V-notch weir box included a flow baffle to steady orifice discharges. The baffle also served to catch any debris that passed through the orifice during the debris laden water tests.

2.3 Debris Material Used

A total volume of 5 x 10^{-3} m^3 of debris material was added to the tank for the "debris laden tests". The material was used to simulate a high concentration of stormwater debris that would be found in some OSD systems located in suburban and bushland catchments. The debris material used is not representative of all catchments.

The debris material comprised approximately:

- 70% of fallen eucalyptus leaves, twigs and bark which was taken from a road gutter in a typical suburban catchment.
- 18% of grass clippings, taken from a lawnmower catch, and;
- 12% of gravel, which was taken from a road gutter in a typical suburban catchment.

Photographs of the debris used to simulate stormwater loadings are shown in Figure 6.

3. TEST PROCEDURE

3.1 Clear Water Tests

"Falling" head tests were used for the clear water case. The procedure for each orifice size was as follows.

1. A gasket was fitted to the back of the orifice plate and the orifice plate was fixed in position.
2. The Maxi-mesh RH3030 screen was fixed in place upstream of the orifice.
3. The tank was filled and the inflow set so that tank-full steady state conditions were achieved.
4. The inflow was turned off and regular measurements were taken of the water level in the tank and at the V-notch weir.
5. Measurements were continued until the water level reached approximately two orifice diameters above the orifice centreline.
6. Steps 3 to 5 were repeated to verify the accuracy and repeatability of results

3.2 Debris Laden Water Tests

For the debris laden tests, material described in Section 2.3 was placed inside the tank. Water was added to the tank and the mix was stirred and given time to saturate.

For the debris laden tests, both "falling" (where discharge is measured with a falling tank water level) and "rising" (where discharge is measured with a rising tank water level) tests were performed. This provided testing of two mechanisms for blocking.

The procedure for each orifice size was as follows.

1. A gasket was fitted to the back of the orifice plate and, with the tank empty, the orifice plate was fixed in position.
2. The Maxi-mesh RH3030 screen was fixed in place covering the orifice, ensuring that no leaves and debris were captured within the screen prior to beginning the test.
3. A rubber plug was fixed in the orifice hole, and the tank was filled. Once full, the tank was stirred to ensure that the stormwater debris was suspended.
4. The rubber plug was released and regular measurements were taken of the water level in the tank and the V-notch weir (i.e. falling head test). The orifice exit was

examined during the test to observe any blocking, and the tank was occasionally stirred to keep the debris activated.

5. Measurements were continued until the water level reached approximately two orifice diameters above the orifice centreline.
6. The upper compartment of the V-notch weir box was examined for any debris that had passed through the orifice during testing. A record was made and the discharged debris was collected and returned to the main tank to ensure that the same concentration of debris was present for the next test.
7. An appropriate flow was delivered using the rotameters and regular measurements were taken of the water level in the tank and at the V-notch weir until the tank was full (i.e. Rising head test).
8. Step 6 was repeated.
9. A further falling head test (steps 4 - 6) was performed for the 50, 40 and 30 mm orifices.

4. RESULTS

Each test undertaken provided a number of timeseries (depending on the number of tests undertaken) of head measurements inside the tank and discharge flows through the orifice.

Equation 2 presents the standard orifice equation. The values of C_D quoted henceforth in this study are determined as the effective C_D of both the Maxi-mesh RH3030 screen and the orifice combined as the head values inside the tank were measured upstream of the Maxi-mesh RH3030 screen.

$$Q = C_D A (2gh)^{\frac{1}{2}} \tag{2}$$

where Q = discharge (m^2 /s)
A = area of the orifice (m^2)
g = acceleration due to gravity (m/s^2)
h = depth of water above orifice (m)

Plots showing the calculated C_D versus head above orifice for the clear water and debris laden tests are shown in Figures 7 to 13 for the 50, 40, 30, 20, 15, 10 and 5 mm orifices respectively. Error bars in these figures are based upon a possible error of + / - 0.5 mm in the water level follower readings. All tests are falling head tests unless otherwise indicated on the plots.

Table 1 provides the C_D value representative of each orifice size for both the clear water and debris laden tests. No C_D value is provided in the instances where the debris laden tests resulted in too great a variability.

Table 1
Representative C_D Values

Orifice Size	C_D in Clear Water Tests	C_D in Debris Laden Tests
50	0.62	0.62
40	0.61	0.62
30	0.63	0.62
20	0.61	0.58
15	0.64	-
10	0.60	-
5	0.55	-

Average C_D values for the orifice plates tested under clear water conditions ranged from 0.64 to 0.55. The lowest average values were recorded for the 5 and 10 mm orifice sizes. For the clear water tests, the maximum possible scatter in data was less than 6 % for the 30, 40 and 50 mm orifices and less than 16 % for the 20, 15, 10 and 5 mm orifices.

C_D values for the orifice plates tested under debris laden water conditions ranged from 0.62 to 0.33. The scatter in data was less than 6 % for the orifices 20 mm and larger, but was up to 60 % for the 15, 10 and 5 mm orifices due to blockage by debris.

It should be noted that the debris laden tests are based on only one type of debris material. This material is typical of suburban and bushland catchments, but other materials may provide different results.

In general, only small quantities of debris were found to pass through the orifices during testing. The material found in the V-notch weir box after testing comprised mostly fine grass and leaf matter and some fine silt, with one or two small leaves. The quantity of debris passing the orifice for each test was less than 2 cm^3.

In summary, results for orifice sizes greater that 30 mm are similar for clear and debris laden water tests, suggesting that orifices larger that 30 mm will not be affected by any debris that passes the maxi-mesh RH3030 screen. The 20 mm diameter orifice appeared to be occasionally influenced by debris but the total indicative C_D value is not dissimilar to the clear water tests. For diameters of 15 mm and irregular blockage of the orifice was observed which resulted in highly variable and substantially decreased C_D values.

5. RECOMMENDATIONS

This study was commissioned to determine how small an orifice in an OSD system can be and still achieve an outflow able to be reliably predicted using the standard orifice equation. The latter requires a predictable coefficient of discharge (C_D).

A previous study for the UPRCT by the Manly Hydraulics Laboratory "Orifice Discharge Control for On-Site Stormwater Detention Systems" (Report MHL657, October 1993) recommended a C_D value of 0.62 be used for all orifices large than 50 mm diameter.

The current WRL study examined orifices less than 50 mm diameter which were placed downstream of a maxi-mesh RH3030 screen. Assuming that the debris laden water used in this study is typical of what commonly flows into OSD systems, the results suggest that a C_D value of 0.62 is also appropriate for orifices from 50 mm to 30 mm in diameter in both clear and debris laden water.

Flows through the 20 mm orifice were effected by the debris. The average clear water C_D value was 0.61 and the average debris laden C_D value was 0.58. This does not necessarily exclude the use of a 20 mm orifice in debris laden water when placed downstream of a maxi-mesh RH3030 screen. However, the designer must be aware the C_D values in debris laden waters will fall from clear water values. An estimation of the C_D values for orifices with diameters between 30 and 20 mm could be made by interpolation with a possible error of ± 3%.

Flows through orifices with diameters 15 mm and smaller were significantly effected by debris that passed the RH3030 screen, with blockages becoming more regular and flows increasingly unsteady for smaller diameters. The results suggest that orifices less than 20 mm should not be used due to the possibility of blockage and the fact that those C_D values could not be reliably determined.

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SCHEMATIC OF TEST RIG

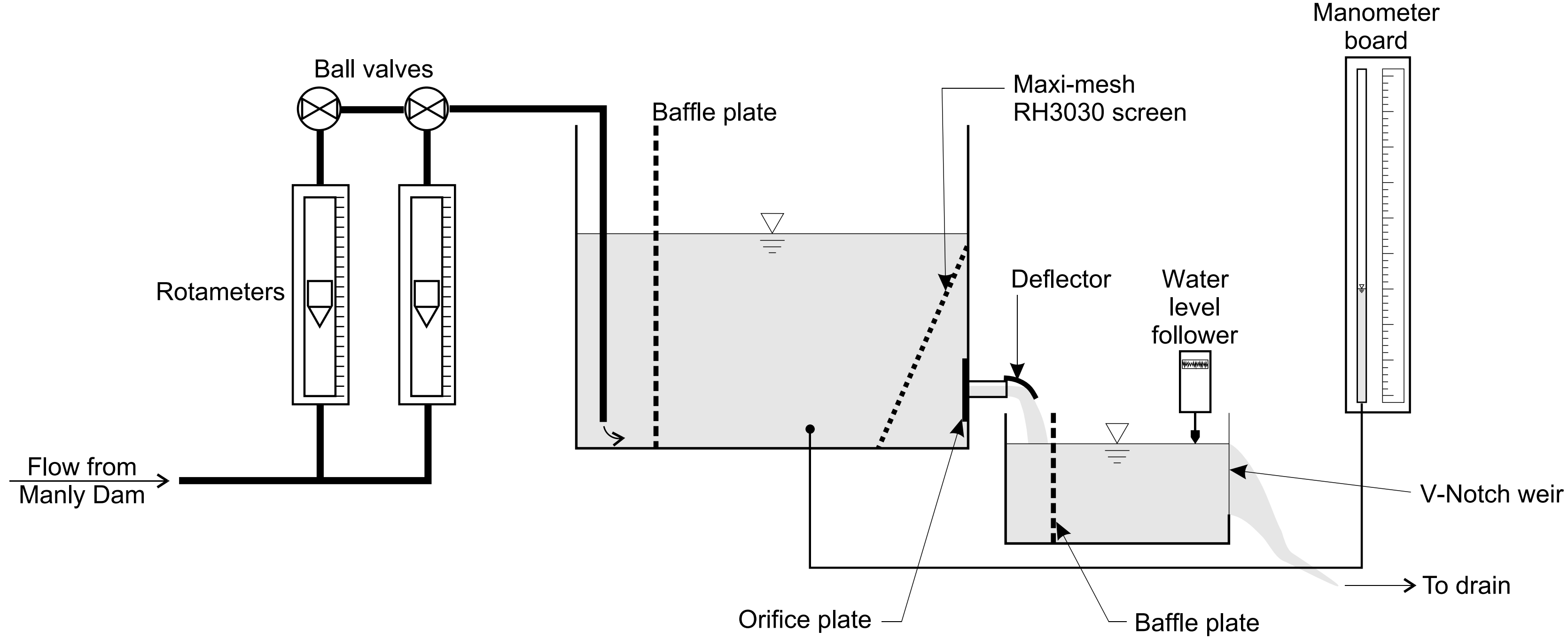

Figure
1

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WRL Report No. 2004/05	INSIDE OF TANK SHOWING ORIFICE PLATE POSITION AND MAXI-MESH RH3030 SCREEN	Figure 2

OUTFLOW CONDITIONS

WRL Report No. 2004/05	V-NOTCH WEIR AND WATER LEVEL FOLLOWER	Figure 5





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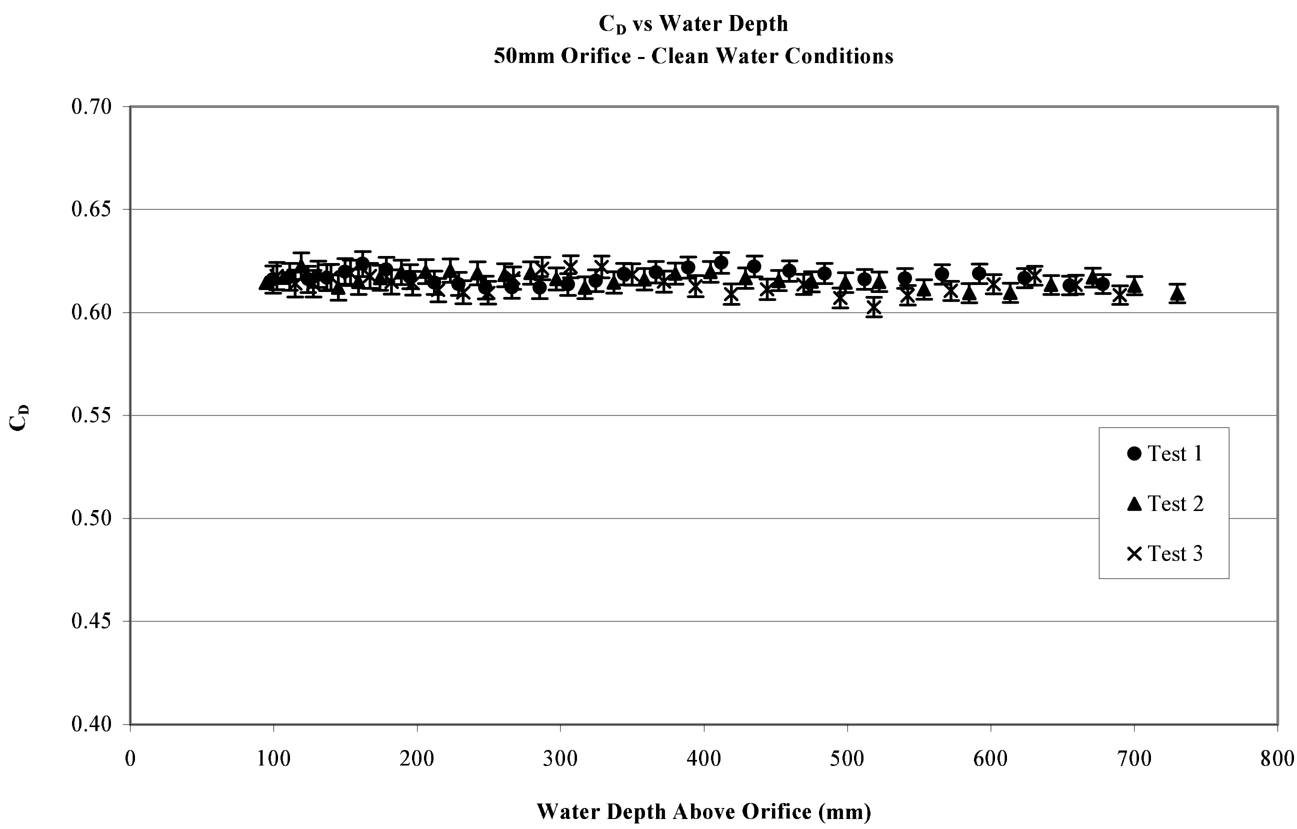

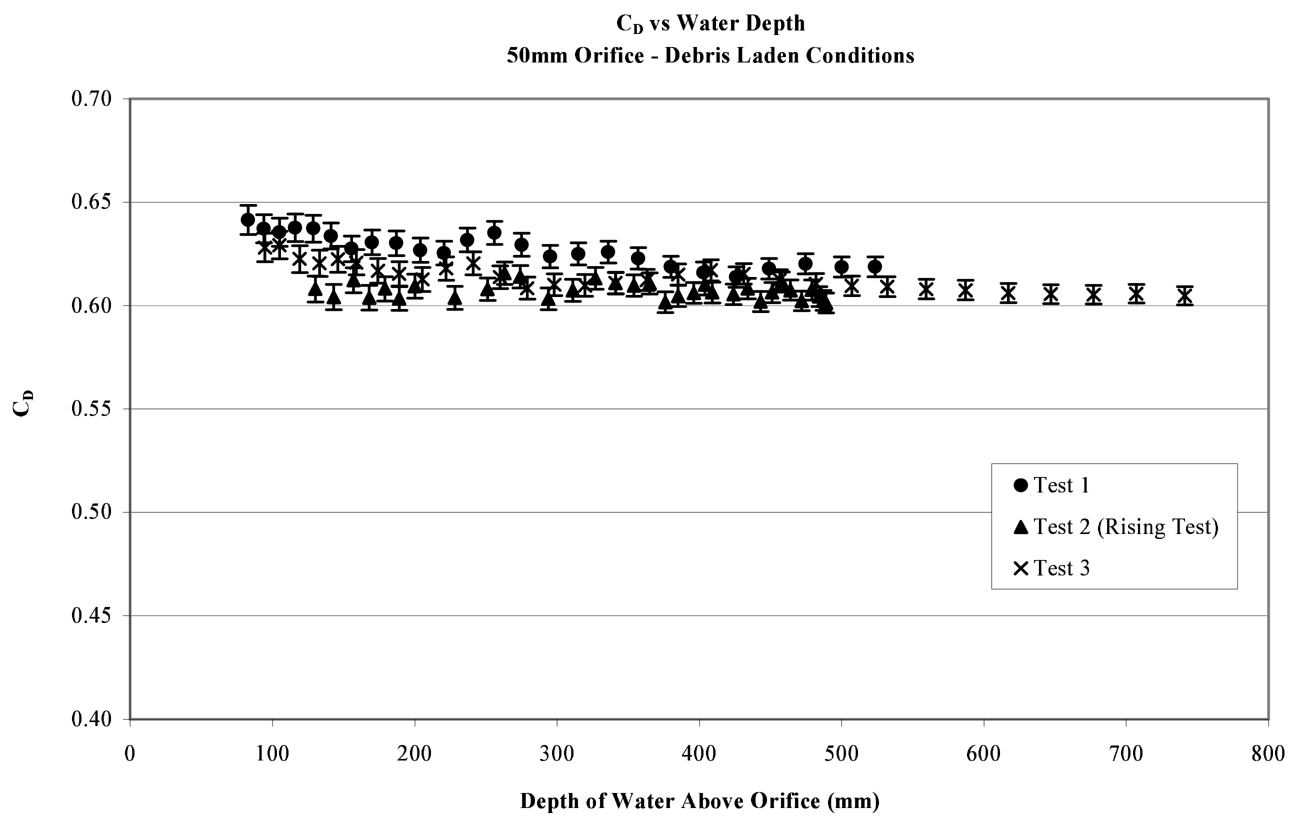

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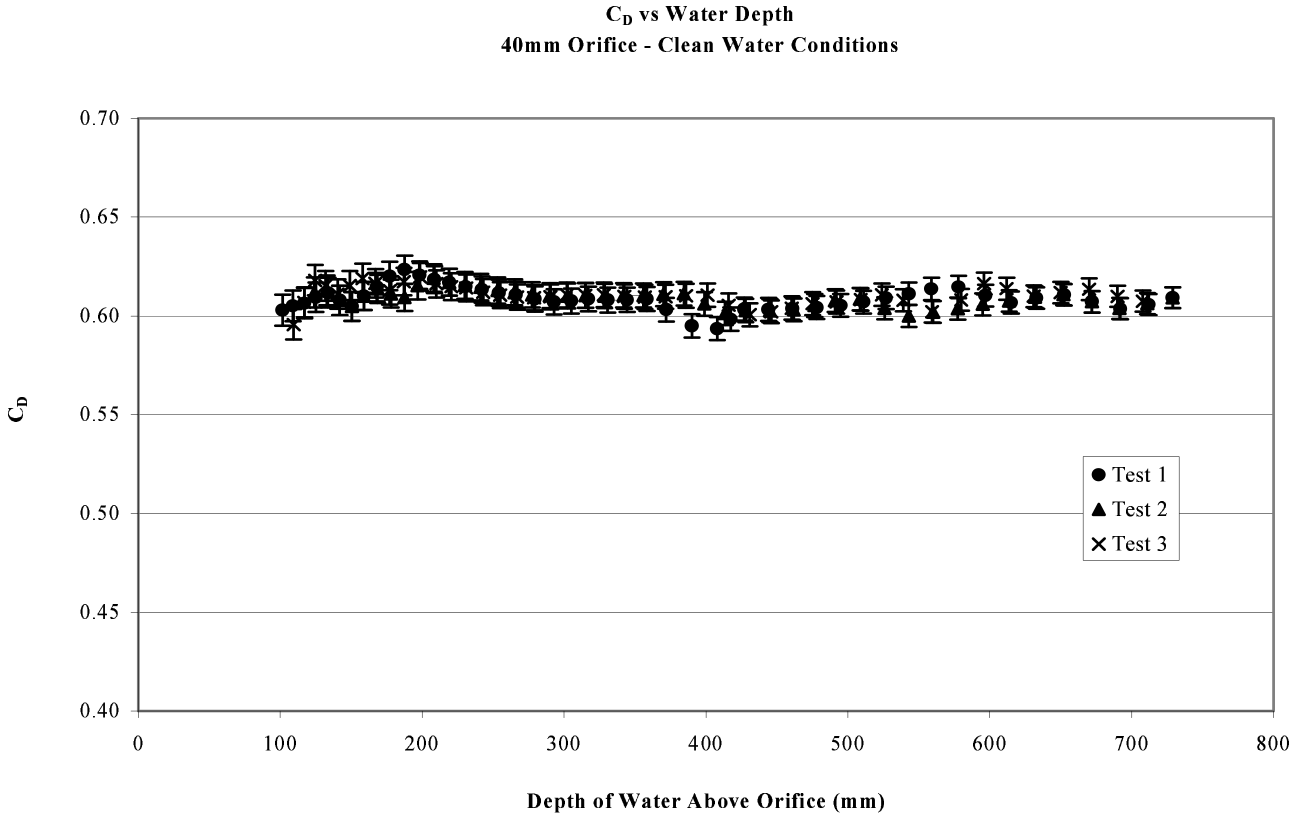

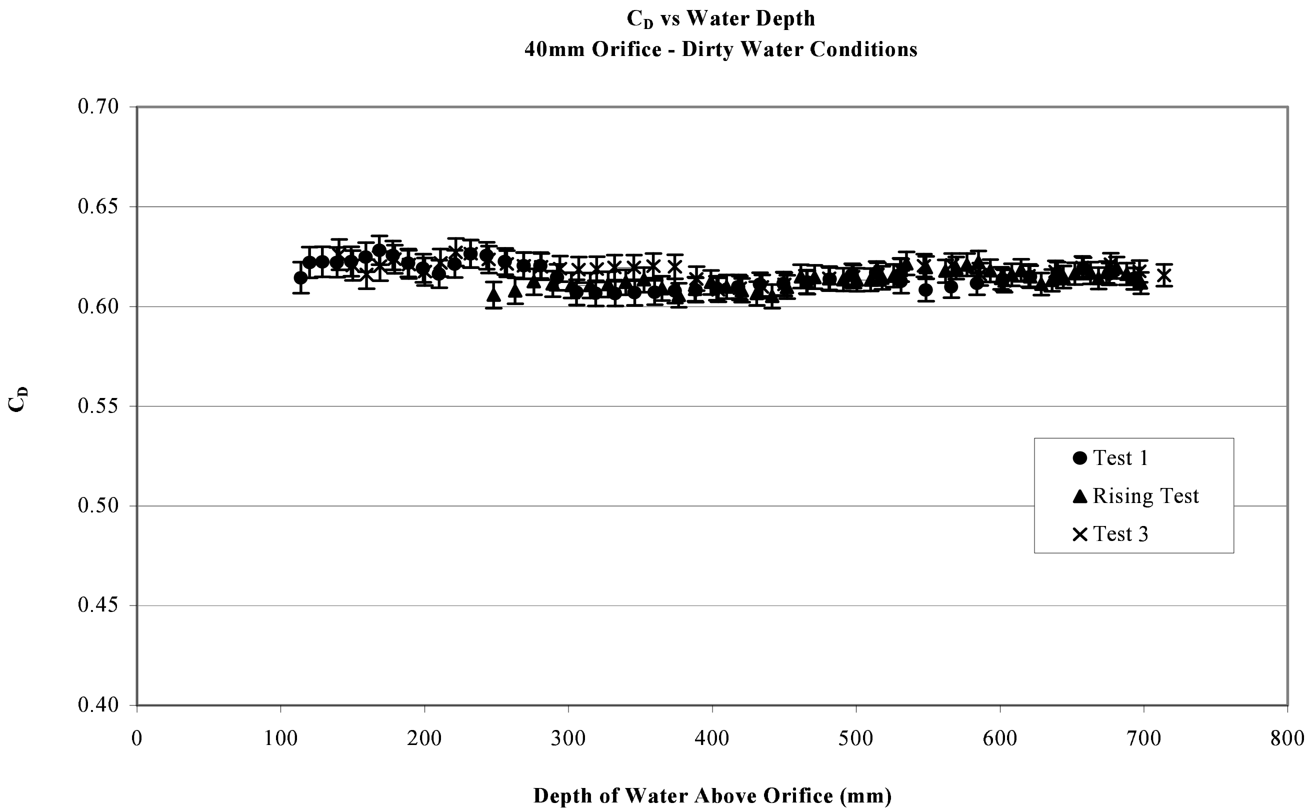

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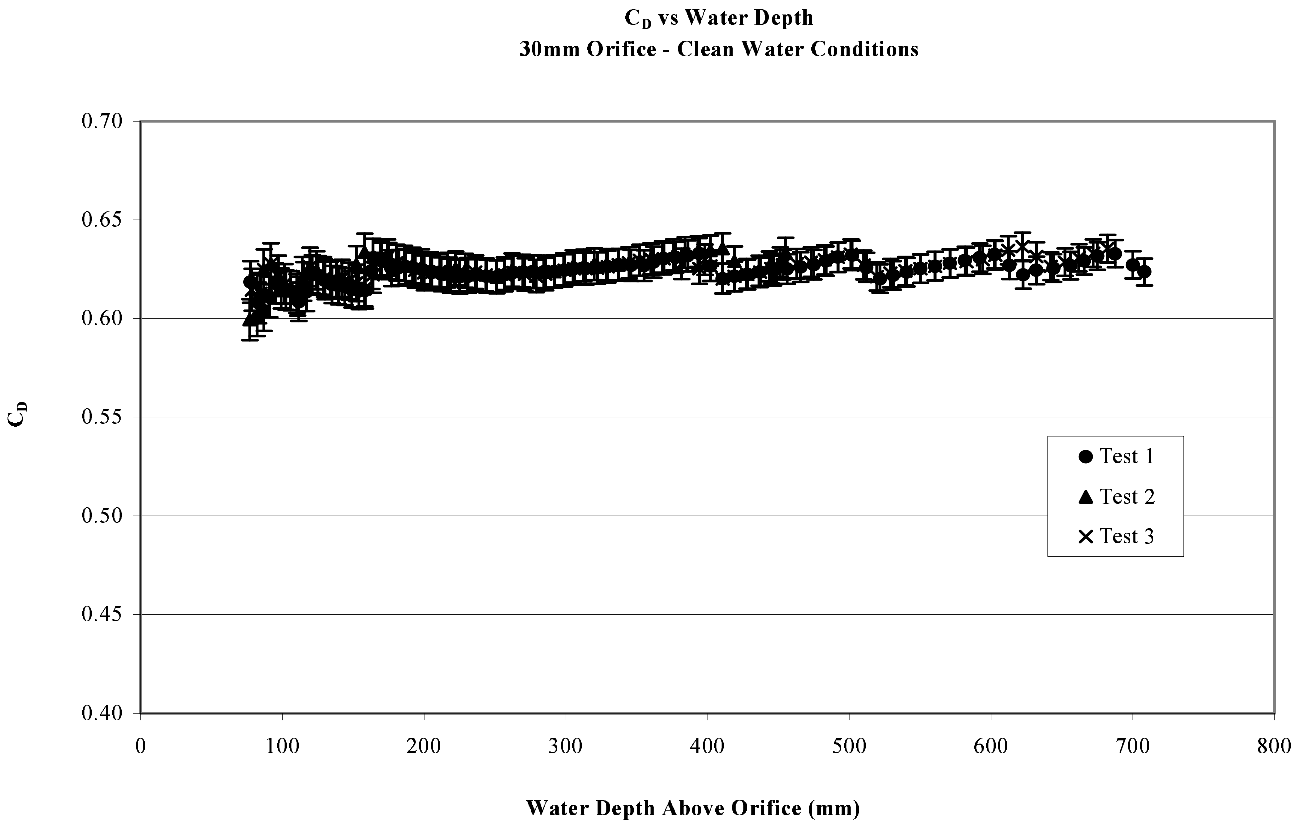
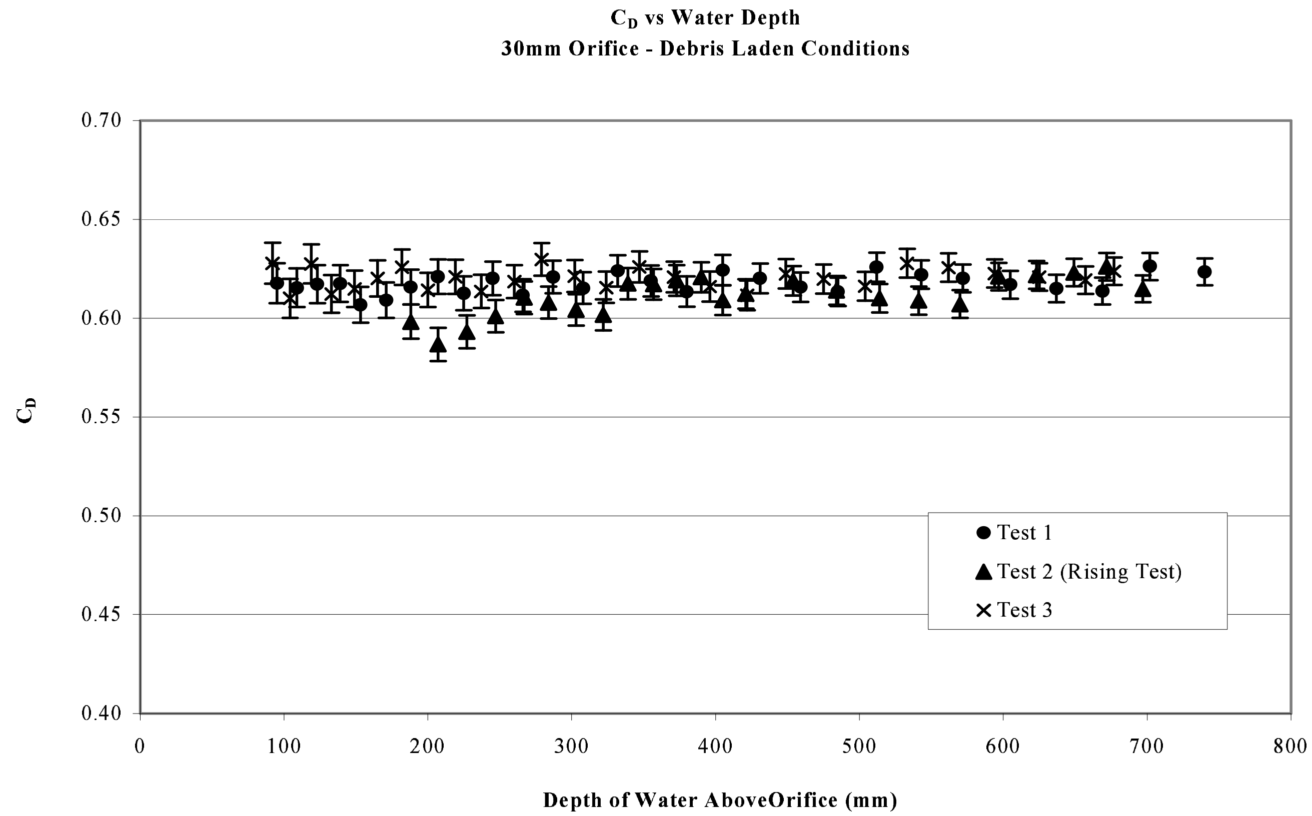
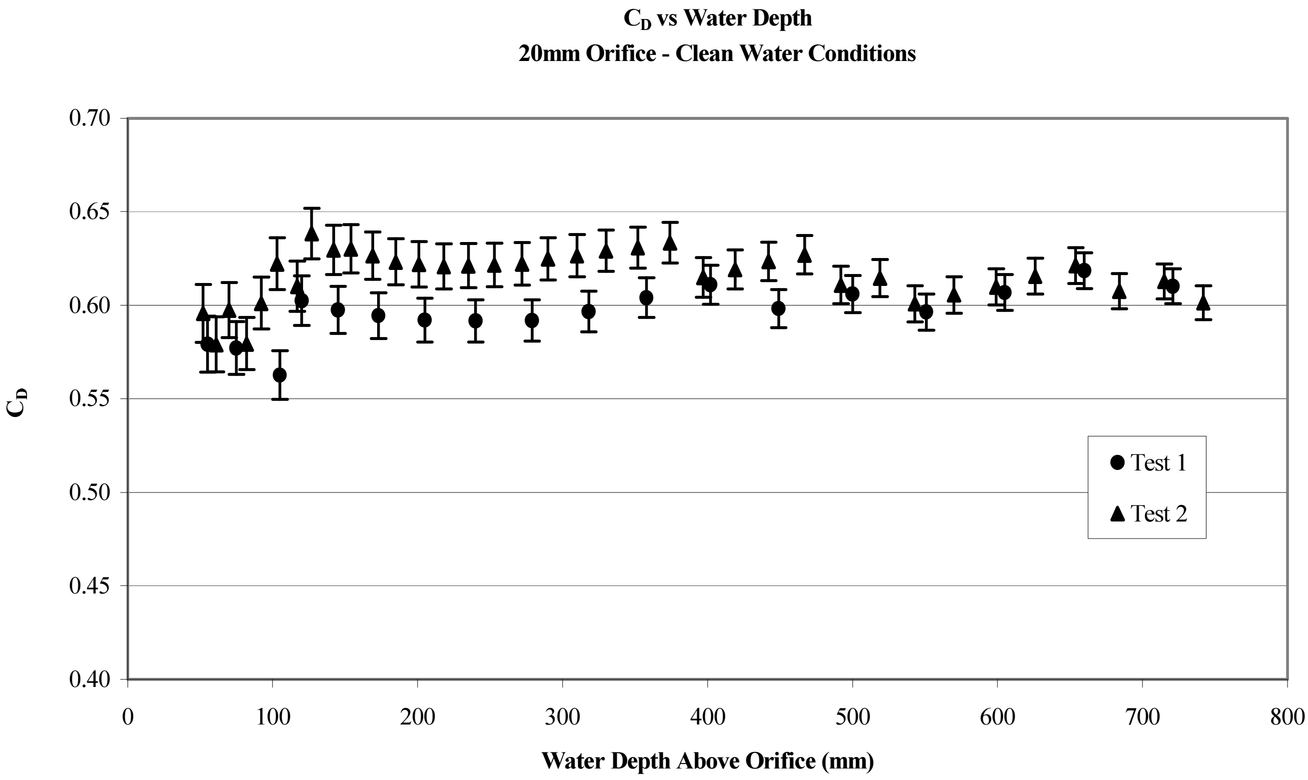
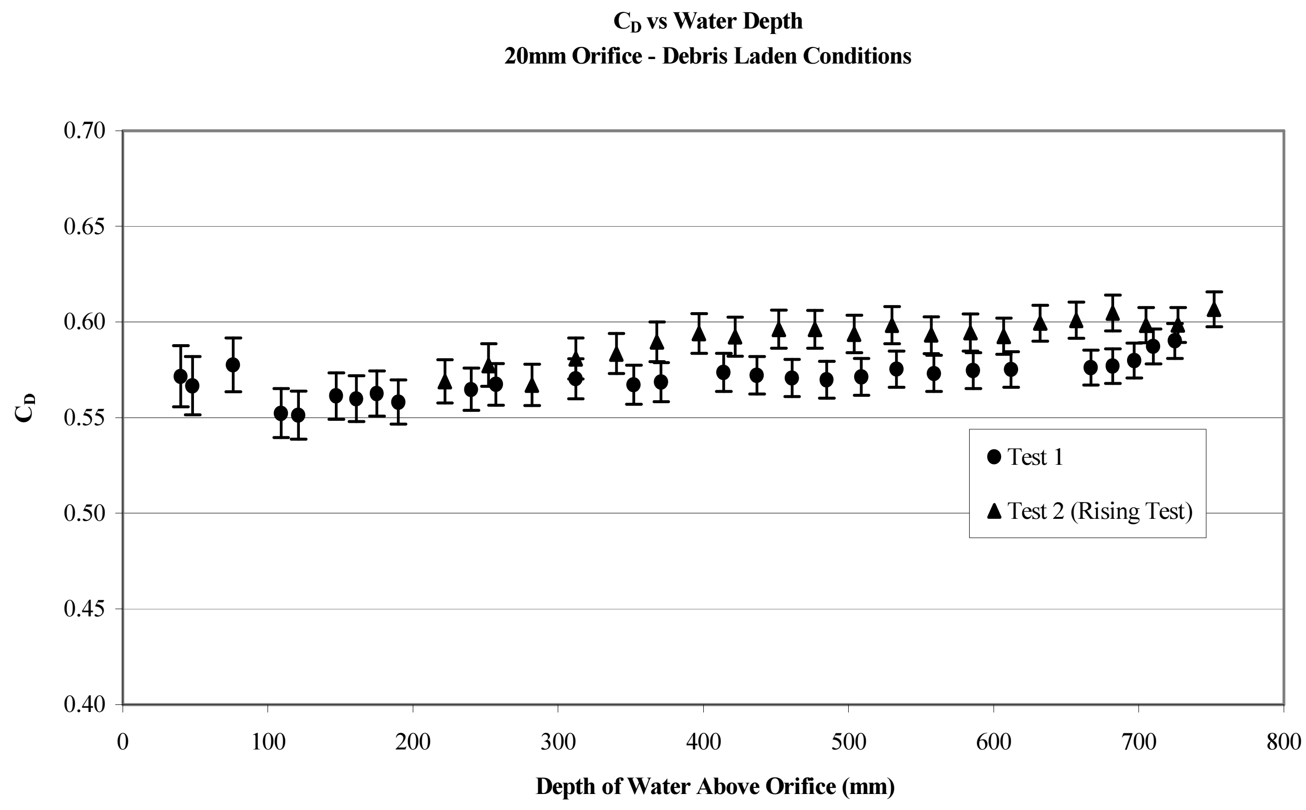




WRL Report No. 2004/05	C_D VERSUS WATER DEPTH FOR THE 30 MM ORIFICE WITH MAXIMESH - CLEAR WATER AND DEBRIS LADEN CONDITIONS	Figure 9





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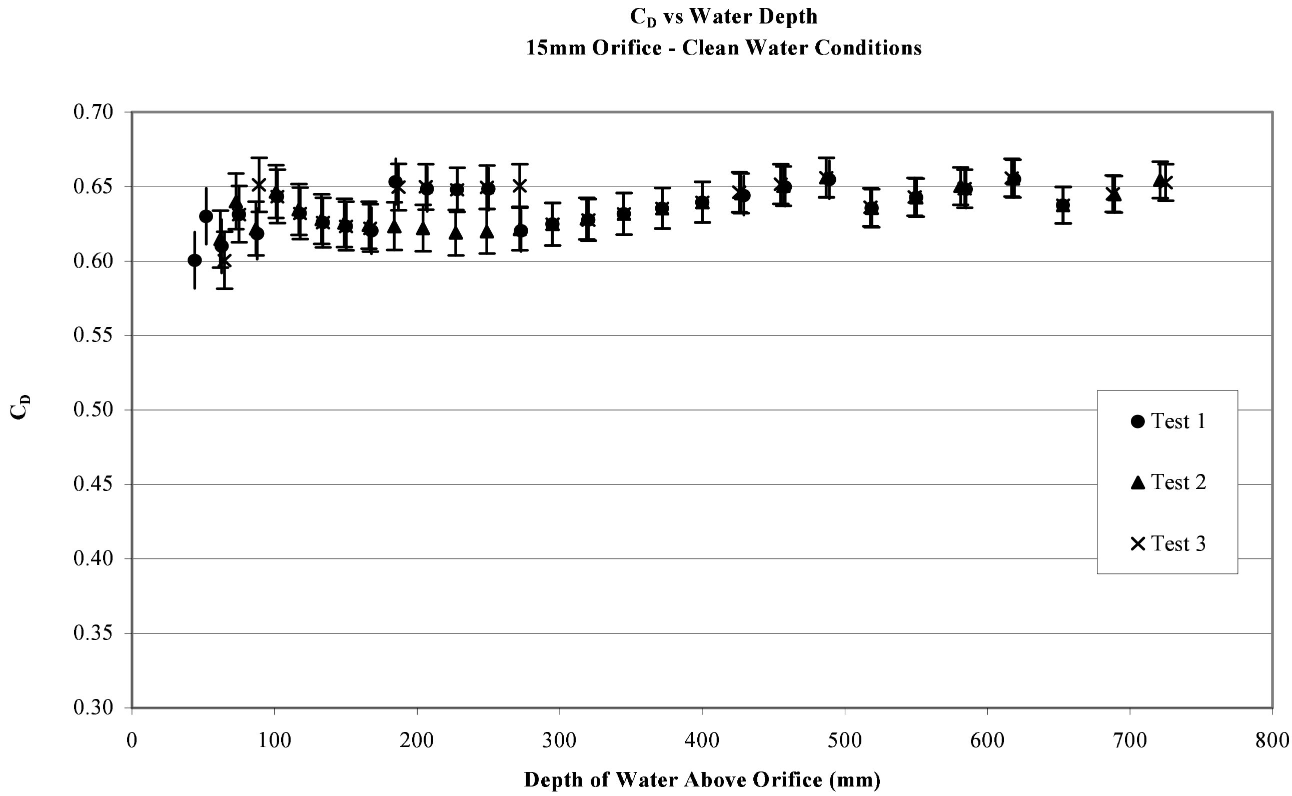

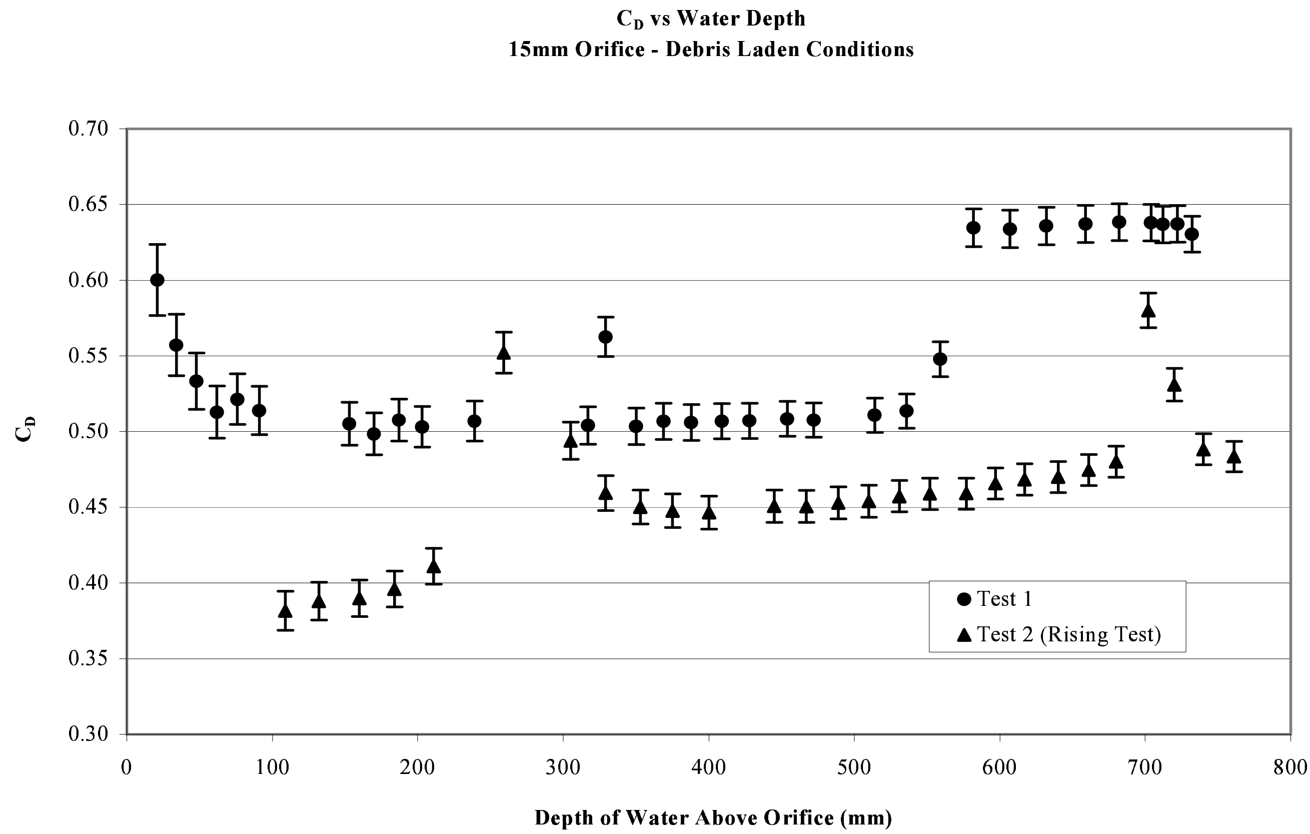

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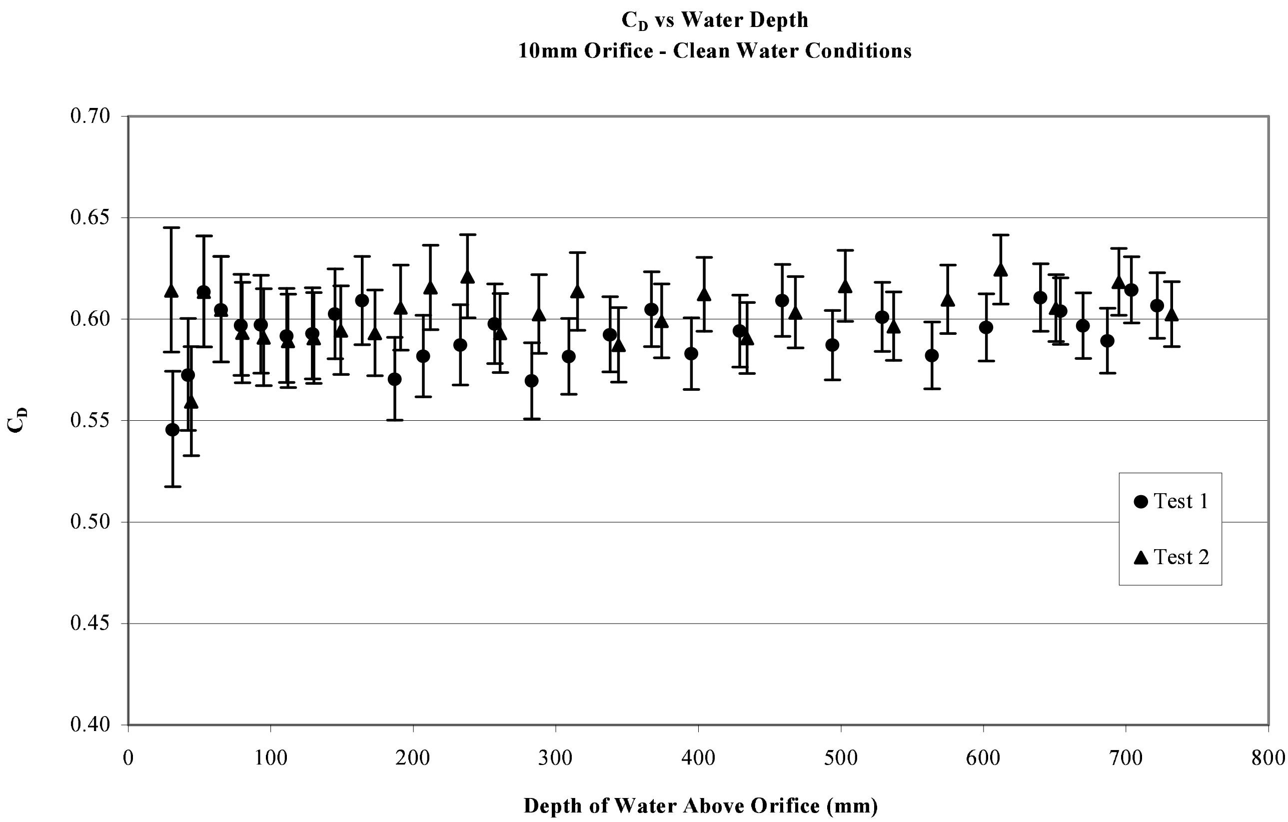

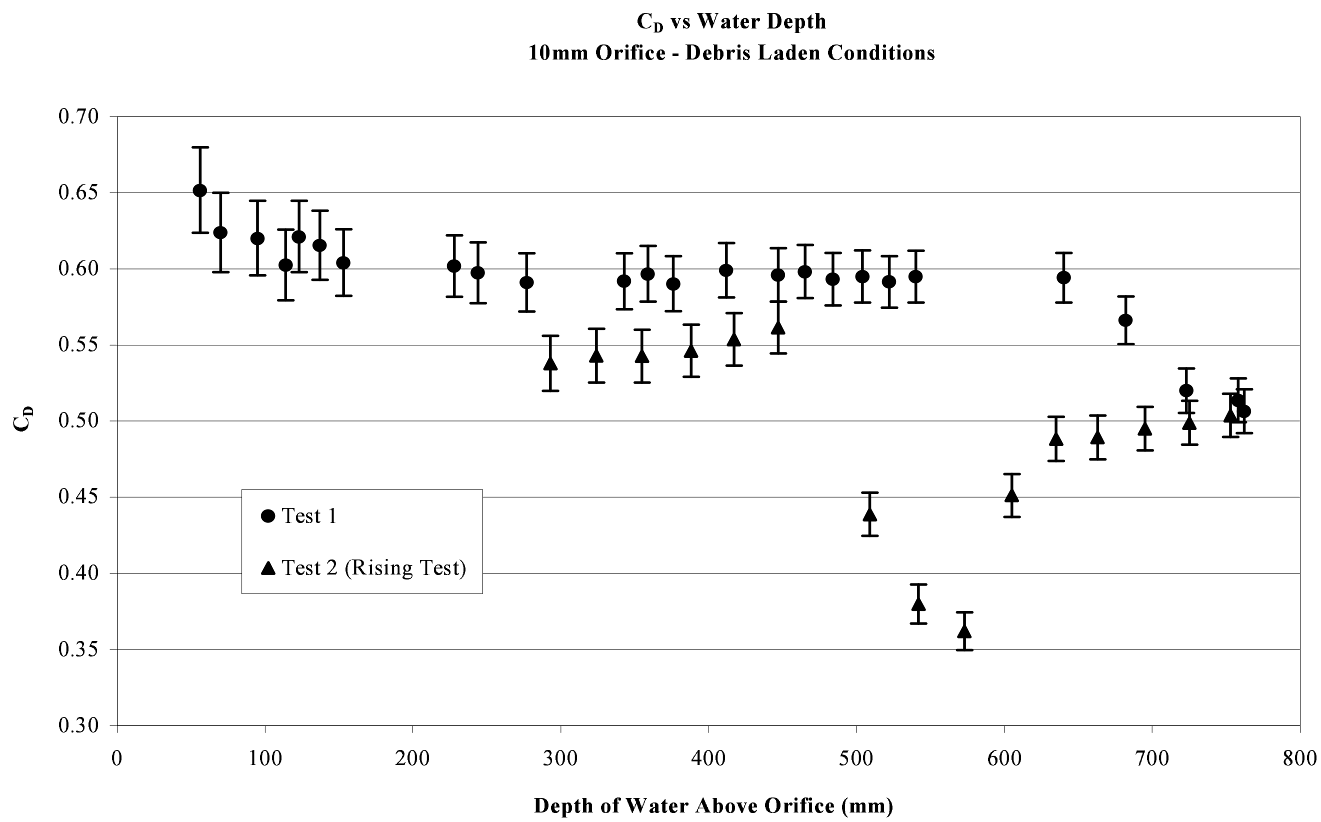

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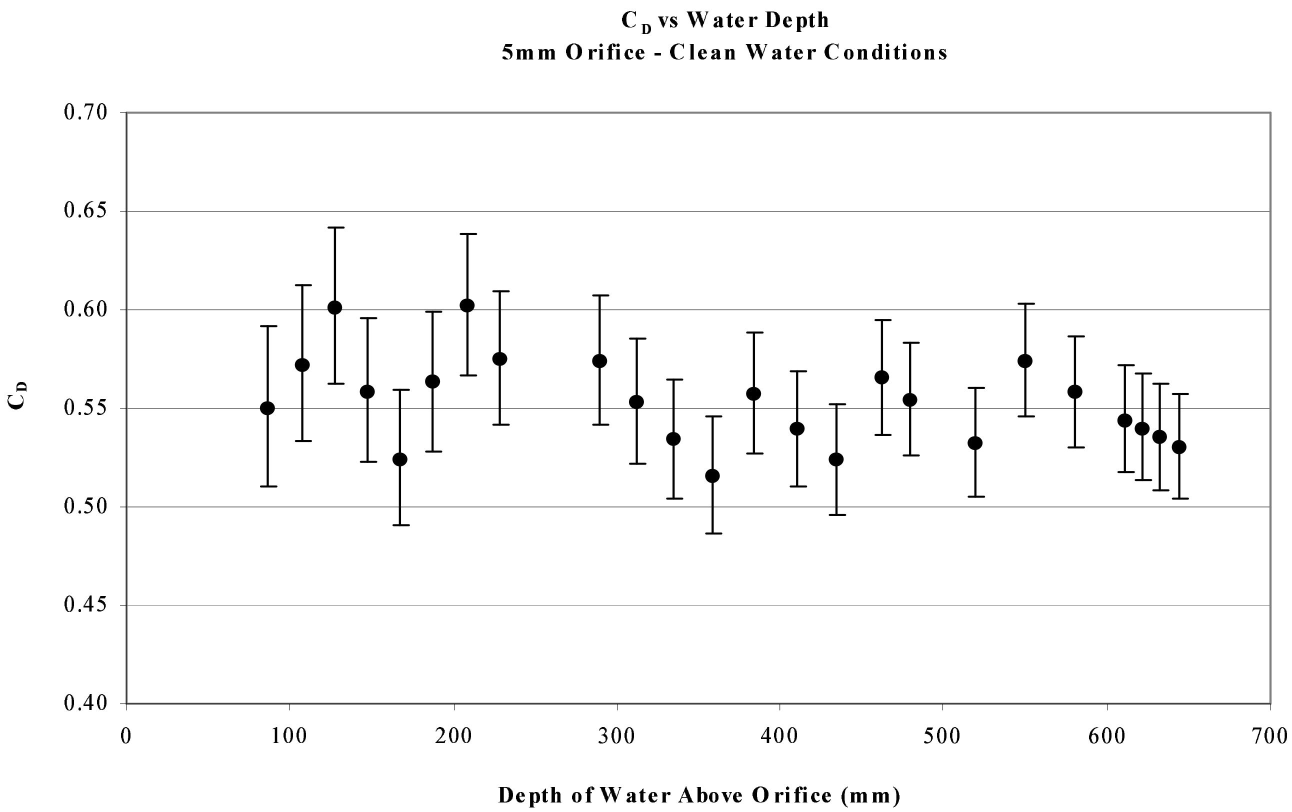

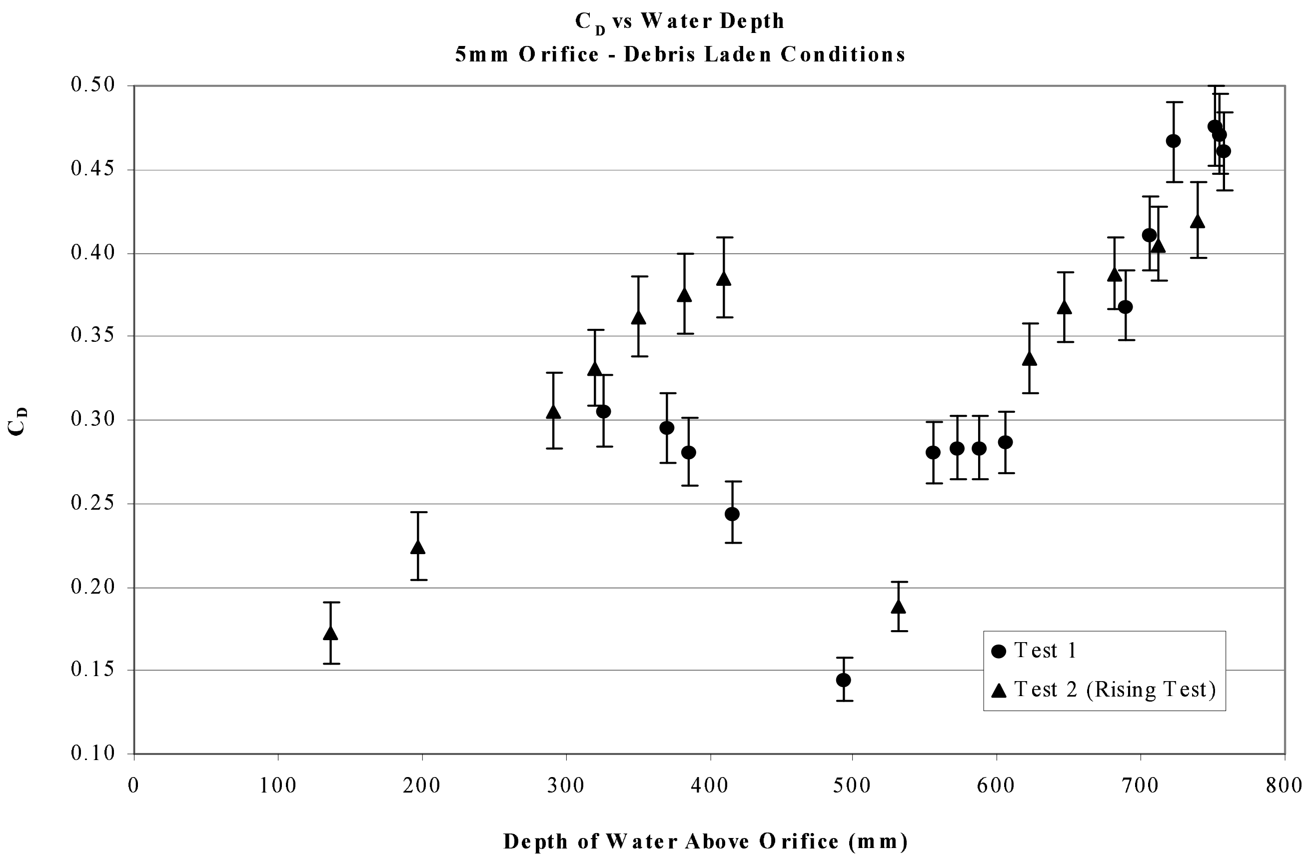

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