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HYDRAULIC PERFORMANCE OF SMALL SCALE BRIDGE DECK DRAINS

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16. Abstract
Efficient removal of stormwater runoff from bridge deck surfaces is an important safety issue. This study investigates hydraulic performance characteristics of a new type of rectangular bridge deck drain. A physical modeling study was conducted to evaluate the hydraulic performance of the innovative rectangular bridge deck drain as a function of the approach discharge, different drain configurations, and bridge characteristics. Experiments included different numbers of open drains in series for variable approach discharge cross slope and longitudinal slope. Measurements included gutter flow depth (Y) and ponding width (T) at different stations along the deck, and the capture discharge and bypass discharge. A model equation is presented for predicting the capture discharge as a function of drain size ($L+W$), the number of open drains (N), Manning's coefficient (n), depth of approached gutter flow (Y), longitudinal slope (S_0), and cross slope (S_x). For experiments considering one through five drains in series (1-5 drains), the rating curve for each individual drain is the same when the drain size is 4 by 8 inches; however, the rating curve decreases slightly with successive drains when the drain size is 6 by 8 inches.

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Bridge deck drain, Capture discharge, Approach discharge, Gutter flow depth, Hydraulic performance

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Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. The engineer in charge of the project was Mr. Matthew Jasso, P.E.

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Chapter 1. Introduction

1.1 Background

Removal of precipitation from bridge decks is an important aspect of highway safety. Due to their elevation above the ground surface, bridges are limited in the type of drainage structures and bridge deck drains are often used (Smith and Holley, 1995). Poor bridge deck drainage is rarely a direct cause of structural failure. However, proper drain design provides benefits related to traffic safety, maintenance, structural integrity and aesthetics (Brown, et al., 2009). A new type of rectangular deck drain "scupper" developed by Texas Department of Transportation (TxDOT) Bridge Division as shown in Figure 1-1 takes into account these concerns. The rectangular drain consists of a drain pan and a drain grate. The drain pan, which is made from standard hollow structural steel tubing, fits between the deck reinforcement with the top of the drain flush with the road surface, and the pan does not interfere with the structural connections of the bridge rail to the deck. The grate is placed over the top of the drain pan to prevent clogging and to provide safety for pedestrians, bicyclists, and vehicles. The drain pan captures stormwater runoff from the decking surface. The captured flow can discharge directly to the air or be routed through a conveyance system depending on the bridge configuration. The rectangular deck drains can be used on long bridges, bridges in urban areas with traffic or pedestrian features, and bridges above environmentally sensitive areas. Such bridges are found in every district of Texas. Therefore, there is a need to study the hydraulic performance of the rectangular scupper.

Figure 1-1 New Type of Rectangular Deck Drain (Pictures Provided by TxDOT)

One of the objectives of bridge deck drainage is to remove runoff quickly and efficiently. A proper design must control the spread of water into traffic lanes, and prevent the accumulation of significant depths of water to reduce the risk of hydroplaning. For design of drainage systems, accurate equations are necessary to determine the amount of runoff intercepted by a typical drain and the ponding width on the bridge deck. Such equations are not available for the new type of rectangular deck drains. Therefore, equations developed by the Federal Highway Administration's (FHWA) Hydraulic Engineering Circle 22 (HEC 22) for slotted drains were adapted to model hydraulic performance. To apply these equations, two approximations have been made: 1) the combined length of the rectangular drains in a series are added without consideration of the intermediate concrete to calculate the effective length of a slotted drain; and 2) the difference in drain width between rectangular drains and slotted drains (2 inches) has been neglected. The use of the FHWA slotted drain equations raises concerns in terms of the accuracy of predicted hydraulic performance, and therefore it is necessary to evaluate whether the adapted equations are accurate or a new equation should be developed to predict the hydraulic performance of the rectangular deck drain.

1.2 Objective

The objectives of this study are to assess whether

- the slotted equation provides accurate prediction of rectangular drain hydraulic performance;
- a correction factor can be applied to the equation; and
- a new set of equations needs to be developed.

1.3 Approach

The primary variables that influence the amount of flow captured by bridge deck drains are longitudinal slope, cross slope, approach discharge, Manning's roughness coefficient, flow regime, drain size, and geometry. Obtaining a mathematical solution for the amount of flow captured is a very complex problem and requires verification against experimental results. Therefore, the primary approach for accomplishing the project objectives was to construct a full-scale physical model of a bridge and conduct a large number of experiments to cover the expected flow conditions and geometries of bridge deck drains.

Chapter 2. Literature Review

Various reports have been published about the hydraulic behavior of curb inlets, grate drains, slotted drains, and scuppers (Izzard 1950; Li 1954; Johnson and Chang 1984; Holley et al. 1992; Young, Walker, and Chang 1993; Smith and Holley 1995; Charbeneau, Jeong, and Barrett 2008; Brown et al. 2009). Grate, slotted, and scupper drains are used in a variety of ways on bridges. The grate inlets tend to be much larger than scuppers and differ in their types of grates, sizes, and orientation. They perform well over a variety of grades but have the disadvantage of becoming clogged with floating trash and debris (Brown et al. 2009). Slotted inlets are very useful to intercept sheet flow; however, they are easily clogged due to the thin width of the inlet (Brown et al. 2009). A scupper drain creates a void in the bridge deck surface. Circular scuppers were investigated by Johnson and Chang (1984), and rectangular scuppers were later investigated by Holley et al. (1992).

2.1 Gutter Flow

Two types of cross slope sections utilized on roadways are uniform and composite as shown in Figure 2-1 and 2-2. A uniform cross slope section consists of a uniform cross slope across the entire width of the roadway (or to the centerline). A composite gutter section uses two different cross slopes: S_x and S_w. S_x is designed for traffic flow, and S_w is designed to increase the cross slope into the gutter. A composite gutter section has a higher hydraulic capacity for normal cross slopes, but bridge deck construction requires a uniform cross slope for structural reasons (Young, Chang, and Walker 1993).

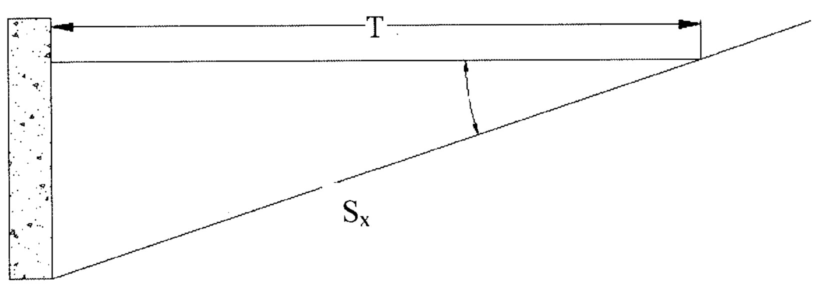

Figure 2-1 Uniform Cross Slope Section (Johnson and Chang 1984)

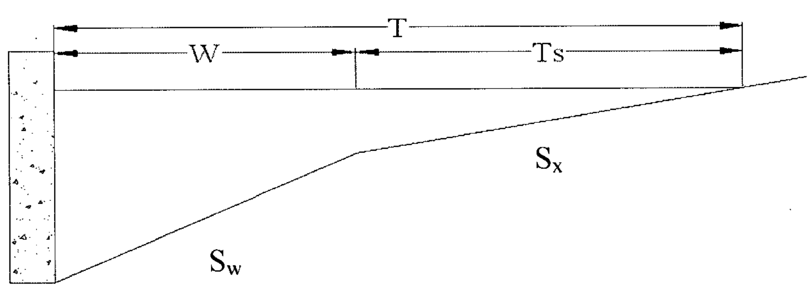

Figure 2-2 Composite Gutter Section (Johnson and Chang 1984)

Manning's equation predicts the flow velocity in the open channel when the flow is driven only by gravity (Houghtalen, Akan, and Hwang 2010, 186–191). Modifying Manning's equation is necessary to predict the gutter flow because the hydraulic radius does not accurately describe a uniform, gutter cross section, especially where the top of the water surface may be 40 times as large as the depth at the curb (Brown et al. 2009). Assuming the bridge is of uniform cross slope and the wetted perimeter is equal to the ponding width or spread, Manning's equation can be modified in terms of the ponding width, also known as Izzard's equation (Izzard 1950), as follows:

$$Q = \frac{k}{n} S_x^{5/3} S_0^{1/2} T^{8/3} \tag{2.1}$$

where Q = flow rate (ft^3/s)
k = 0.56 for English units (0.377 for SI units)
n = Manning's roughness coefficient
S_x = cross slope (ft/ft)
S_0 = longitudinal slope (ft/ft)
T = ponding width (ft)
y = water depth

Then T can be written as

$$T = \left(\frac{Qn}{k S_x^{5/3} S_0^{1/2}} \right)^{3/8} \tag{2.2}$$

and

$$T = \frac{Y}{S_x} \tag{2.3}$$

By combining Equation 2.2 and 2.3, the water depth (y) can be found in Equation 2.4:

$$Y = \left(\frac{Qn S_x}{k \sqrt{S_0}} \right)^{3/8} \tag{2.4}$$

Water depth is an important factor to determine whether hydroplaning occurs, because an empirical formula for the initiation of hydroplaning at a particular vehicle's speed is a function of the tire tread depth, pavement texture depth, water film depth, and tire pressure (Young, Walker, and Chang 1993). A minimum cross slope of 2% is recommended and has little effect on driver stability and pavement friction (Gallaway et al. 1979).

2.2 Flow over a Free Drop

After Izzard's study, Li (1954) made a comparison between flow into a drain inlet and flow falling freely off a channel end to determine the captured discharge by a curb inlet as shown in Figure 2-3. Li (1954) used the equation (2.3) describing the trajectory of a particle of water.

Equation 2.5 was based on the assumption of supercritical flow, uniformly distributed velocity, and neglected air resistance.

$$L_r = V_a \sqrt{\frac{2y}{g}} \qquad (2.5)$$

where L_r = length of the water profile (ft)
V_a = approach velocity (ft/s)
y = flow depth (ft)
g = acceleration of gravity (ft/s^2)

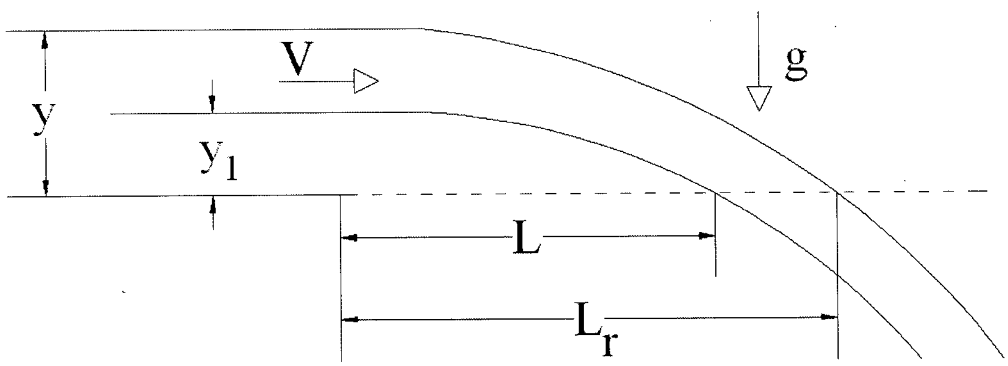

Figure 2-3 Profile View of Free Drop (Li 1954)

In Figure 2-3, if there is an opening of length L in the bottom of the channel, then only the flow between the channel bottom and a depth y_1 is captured by the opening. By calculating the trajectory of a water particle at a distance y_1 from the bottom of the channel, L can be calculated as

$$L = V_a \sqrt{\frac{2y_1}{g}} \qquad (2.6)$$

Using the same approach of a free drop, Li (1954) modified Eq. (2.6) for lateral flow as shown in Figure 2-4. The term *g* was replaced by an acceleration equal to g(cosθ), which is the component of gravity parallel to the cross slope at an angle θ to the vertical (Figure 2-5). The flow depth was replaced by the ponding width *T*, as shown in Figure 2-5.

$$L_r = V_a \sqrt{\frac{2T}{g \cdot \cos\theta}} \qquad (2.7)$$

Using $T = y \tan\theta$, $Q_a = V_a y^2(\tan\theta)/2$ and assuming 100% efficiency ($Q_c = Q_a$), Equation 2.7 becomes

$$\frac{Q_c}{L_r y\sqrt{gy}} = \sqrt{\frac{\sin\theta}{8}} \tag{2.8}$$

where Q_c = captured discharge (cfs)
Q_a = approach discharge (cfs)

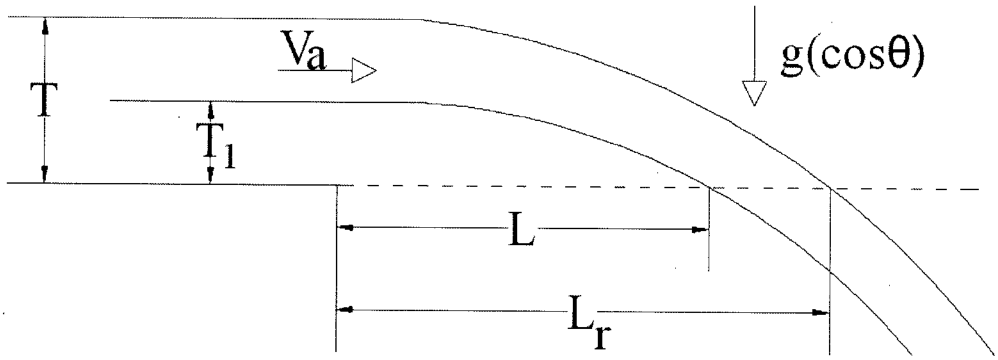

Figure 2-4 Plan View of Lateral Flow (Li 1954)

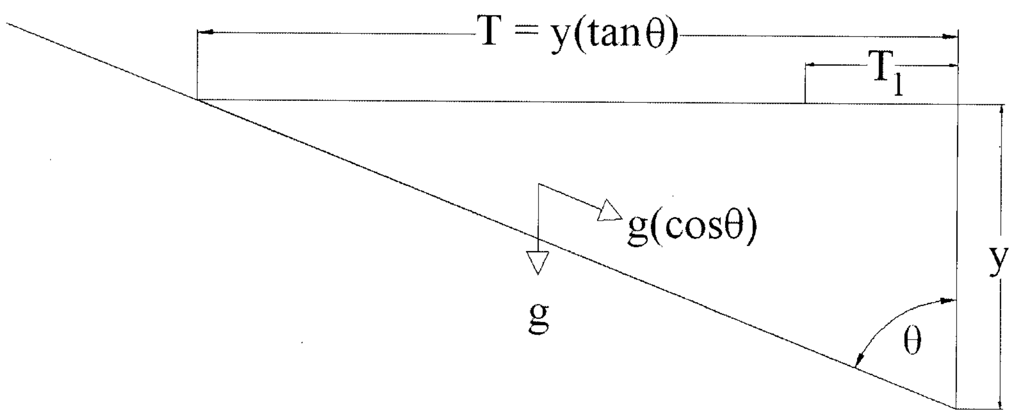

Figure 2-5 Cross Section of Gutter Flow (Li 1954)

According to Li (1954), the flow captured (Q_c) in the opening is the flow having a width of T_1 (Figure 2-5), related as follows:

$$Q_c = \frac{1}{2}V_a\left[yT - y_1(T - T_1)\right] \tag{2.9}$$

2.3 Lateral and Frontal Flow

The Froude Number (N_F) is the ratio of inertial to gravitational forces in the flow (Houghtalen et al. 2010, 200). At critical flow

$$N_F = \frac{V}{\sqrt{gD}} = 1 \tag{2.10}$$

where V = velocity (ft/s)
D = hydraulic depth, D= A/T = cross-sectional area/ponding width (ft)

g = acceleration of gravity (ft/s^2)

For a rectangular channel the critical depth ($y_{c,}$) relation is shown in Equation 2.11 (Houghtalen et al. 2010, 200).

$$y_c = \sqrt[3]{\frac{Q^2}{gb^2}} \tag{2.11}$$

where Q = flow rate (cfs)
b = width of the channel (ft)

By substituting y_c for D in Equation 2.10, the critical velocity head is represented in terms of critical depth.

$$\frac{V_c^{\ 2}}{2g} = \frac{y_c}{2} \tag{2.12}$$

From Equation 2.12, the specific energy (E) at the critical section is shown in Equation 2.13. Neglecting the approach velocity head, the specific energy is approximately equal to the water depth upstream for a frictionless weir (Houghtalen, Akan, and Hwang 2010, 293).

$$E = y_c + \frac{V_c^{\ 2}}{2g} = \frac{3}{2} y_c = y \tag{2.13}$$

Equation 2.13 shows one-third of the specific energy is associated with the kinetic energy, or the velocity head, and two-thirds of the specific energy is associated with the potential energy, or the water depth at critical flow.

One may calculate lateral flow to a section of a drain by assuming critical flow occurs at the edge of the drain, and that the specific energy corresponds to the flow depth upstream of the drain. For such conditions, the lateral discharge per length of the drain is a product of the water depth and lateral velocity as shown in Equation 2.14. This relation is shown in Figure 2-6.

$$q_c = y_c V_c = \frac{2y}{3} V_c = \sqrt{g}\left(\frac{2y}{3}\right)^{3/2} \tag{2.14}$$

If the lateral inflow is uniform along a drain of length *L*, then the drain capture discharge is calculated using Equation 2.15.

$$Q_L = \sqrt{g}\left(\frac{2y}{3}\right)^{3/2} L \tag{2.15}$$

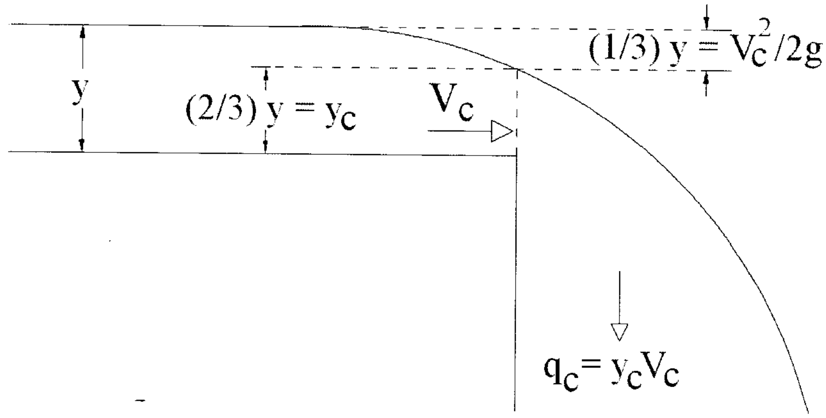

Figure 2-6 Lateral Flow into a Drain Inlet

One may also calculate the frontal discharge to a drain of width W, assuming that the gutter discharge within the section of width W near the curb is captured by the drain. From Izzard's Equation (2.1), the frontal discharge into the drain of width W normal to the curb is

$$Q_F = \frac{k\sqrt{S_0}}{nS_x}\left[y^{8/3} - (y - S_x W)^{8/3}\right] \tag{2.16}$$

2.4 Slotted Drain Analysis

The FHWA method for analysis of slotted drains is the same as that presented by Izzard (1950) for curb inlets. The theory assumes that due to drain inflow, the depth varies linearly from the upstream curb depth Y to zero at capture length L_T for total capture of the approach discharge. With this varying depth along the length of the drain, Equation 2.14 is used to calculate the lateral inflow specific discharge. Replacing $y=LY/L_T$ in Equation 2.14 and integrating this specific discharge along the inflow length L_T gives

$$Q_c = \frac{4}{15}\sqrt{\frac{2g}{3}}\, Y^{3/2}\, L_T \tag{2.17}$$

Comparison of Equation 2.17 and Equation 2.15 is of interest. These equations suggest that for the same capture discharge, a drain system with uniform inflow along its length will be shorter in length by a factor of approximately 2.5 compared with a drain system with linearly varying depth along its length.

Using the FHWA slotted drain method (Brown et al. 2009), the length of slotted drain required can be estimated with Equation 2.18, which is a simplified form of Equation 2.17 when combined with Izzard's equation (Equation 2.1) for gutter flow. Equation 2.18 applies if the width of the slotted inlet is greater than 1.75 inches (Brown et al. 2009).

$$L_T = K_T Q^{0.42} S_0^{\ 0.3} \left(\frac{1}{nS_x} \right)^{0.6} \tag{2.18a}$$

$$Q = \left(\frac{L_T}{K_T S_0^{\ 0.8} \left(\frac{1}{nS_x} \right)^{0.6}} \right)^{1/0.42} \tag{2.18b}$$

where L_T = length of slotted drain inlet required to intercept 100% of flow (ft)
K_T = 0.6 for English units (0.817 for metric)
Q = flow rate in gutter (cfs)
S_0 = longitudinal slope (ft/ft)
S_x = cross slope (ft/ft)
n = Manning's roughness coefficient

The carry-over flow rate can also be calculated like a curb inlet (Brown et al. 2009).

$$E = 1 - \left(1 - \frac{L}{L_T} \right)^{1.8} \tag{2.19}$$

where E = efficiency of interception
L = actual length of slotted drain inlet used (ft)
L_T = length of slotted drain inlet required to intercept 100% of flow (ft)

Using the definition of efficiency, *E* is equal to the ratio of intercepted flow to total flow, and the carry-over flow becomes

$$Q_{co} = Q \left(1 - \frac{L}{L_T} \right)^{1.8} \tag{2.20}$$

where Q_{co} = carry-over flow rate (cfs)
Q = total flow rate (cfs)

See Figure 2-7.

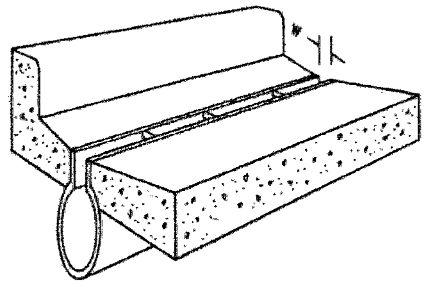

Figure 2-7 Slotted Inlet Drain (Brown et al. 2009)

2.5 Previous Related Studies

Johnson and Chang (1984) studied the 4-in. circular scupper drain and Holley et al. (1992) investigated a rectangular drain with the width of 4 inches and length of 6 inches, and the vertical length of 12 inches. Both studies show similar results for the relationship between water depth and flow rate. The linear relationship between log (Q) and log (y) appear to break at higher flow rate. The break point corresponds to an orifice behavior at a certain flow depth for each slope. Holley et al. (1992) found the flow into the scupper drain behaves as a weir flow along each of four sides for the smaller flow depths with subcritical flow; however, the water does not flow into the scupper from the downstream side for supercritical flow. The data from the literature were compared with this study. The regressive analyses for this study were conducted and compared with the previous studies.

2.5.1 Experimental Results for 4-inch Diameter Circular Scupper (HEC 12 [Johnson and Chang 1984])

Figure 26 in HEC 12 (Johnson and Chang 1984) is replicated as Figure 2-8 with reversed axes. This figure shows the relationship between measured water depths and capture discharges for a 4-in. diameter scupper at different longitudinal slopes at a continuous cross-slope ($S_x = 0.03$). The data for HEC 12's Figure 26 were also tabulated in the database. Figure 2-8 shows two different data slopes for capture discharge/water depth but data slope remains constant for each longitudinal slope. At lower water depths ($y < 0.1$ ft), the capture discharges increased with increased longitudinal slope. However, at higher water depths ($y > 0.1$ ft), the capture discharges decreased with increased longitudinal slope. The reason for the change in the scupper drain behavior is that at smaller depths, the drain behaves as a weir; at larger depths, the drain behaves as an orifice. The break point in Figure 2-8 corresponds to this change in behavior for longitudinal slope $S_0 = 0.002$, 0.01, 0.02, and 0.06 on continuous grade bridge cross slope $S_x = 0.03$ (Johnson and Chang 1984).

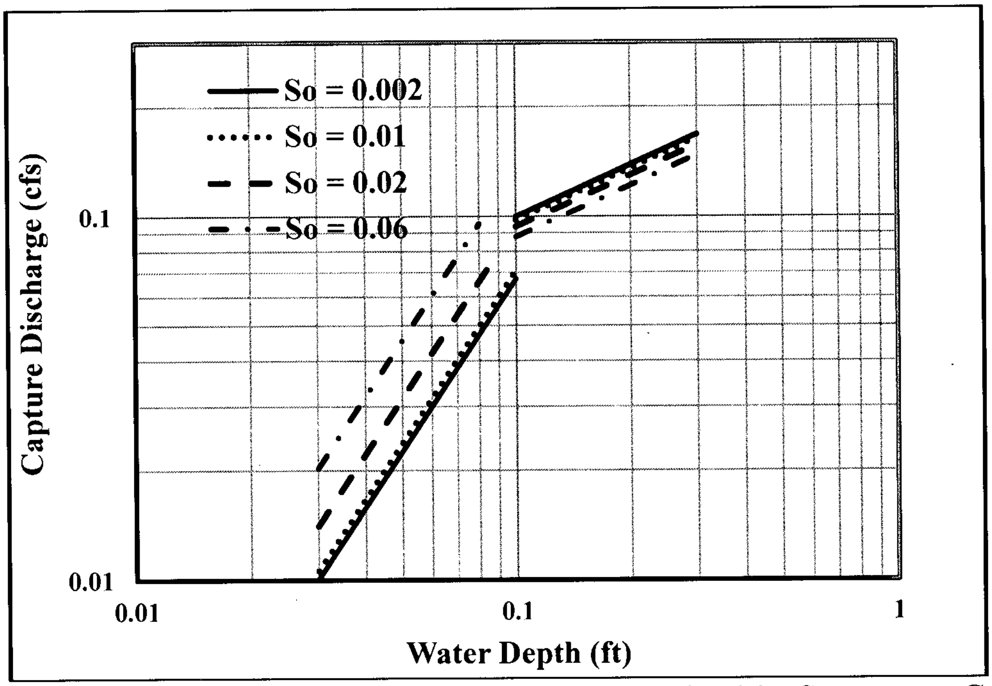

Figure 2-8 Capture Discharge vs. Measured Water Depths for 4-in. Scupper on Continuous Grade Bridge at Sx= 0.03 Modified from HEC 12 with the Reversed Axes (Johnson and Chang 1984)

2.5.2 Experimental Results for 4in. × 6in. Rectangular Scupper (1267-1F [Holley et al. 1992])

The data for a 4in. × 6in. rectangular scupper were entered into the database from TxDOT research report 1267-1F (Holly et al. 1992). The scupper was flush with the bridge deck surface. The water entered the drain and immediately plunged through critical depth as free fall. Seventy-four tests were conducted with bridge deck longitudinal slopes (S_0) of 0.001, 0.005, 0.01, 0.02, 0.04, and 0.06, and cross slope (S_x) of 0.01, 0.02, 0.04, 0.06, and 0.08. The range of total flows (Q) was from 0.03 cfs to 3 cfs. Figure 2-9 shows that the calculated normal water depths varied with the capture discharges. Figure 2-9 (Holley et al.) indicates the same type of break points between weir and orifice flow as in HEC 12 (Johnson and Chang 1984). Holley et al. (1992) attributed the larger capture discharge at the break point (0.16 cfs) to the fact that a larger inlet was being tested than by Johnson and Chang (1984). The "weir like" portion of the data (i.e., before the break point in the slopes of the data) demonstrates that the capture discharges increases with the water depths and longitudinal slopes, but decreases with the cross slopes (Holley et al. 1992).

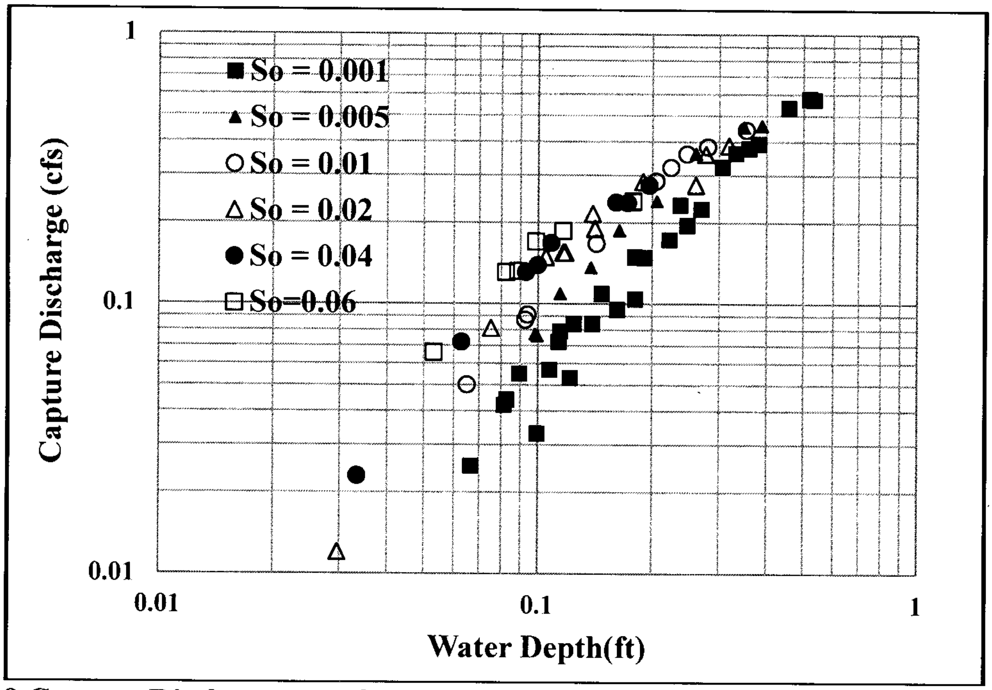

Figure 2-9 Capture Discharges vs. Calculated Normal Water Depths for Rectangular Deck Drain at Different Longitudinal and Cross Slopes (Holley et al. 1992)

2.6 Literature Survey for Other DOTs

A search of state transportation department web sites and nation transportation databases as well as a canvassing of bridge offices produced information on the bridge deck drain design guidance. Tables 2-1 provides information on the scuppers, design guidance, and software used, as well as the links for the references. Scuppers are used by 31 states. Among them, 28 states followed the HEC 12 design guidance. The new type of the rectangular drain is used in Texas and New Mexico. Both states have adapted the FHWA slotted drain design equations. California developed the design equations for scupper in sag and scupper on grade in the Caltrans-Bridge Design Aid (October 2006). The detailed equations and design consideration are developed in the bridge manual.

Table 2-1 Bridge Deck Drainage for All the States

State	Use Scupper	Design Guidance	Reference Link	Software Used
Alabama	Yes	FHWA Report No. RD-79-31, 1979. HEC 21-1993	http://www.dot.state.al.us/brweb/doc/ALDOTStructuresDesignDetailManual.pdf	
Alaska	No			
Arizona	Yes	FHWA Report No. RD-79-31, 1979. HEC 21-1993	http://www.azdot.gov/Highways/Roadway_Engineering/Drainage_Design/PDF/ADOTHighwayDrainageDesignManual_Hydraulics.pdf http://www.fhwa.dot.gov/bridge/hec21.pdf	
Arkansas	No			
California	Yes	Caltrans - Deck Drainage Aids	http://www.dot.ca.gov/hq/esc/techpubs/manual/bridgemanuals/bridge-design-aids/bda.html	
Colorado	No	End Drainage System, HEC 21-1993	http://www.fhwa.dot.gov/bridge/hec21.pdf	
Connecticut	No	End Drainage System. Drainage Manual and HEC 21	http://www.ct.gov/dot/cwp/view.asp?a=3200&q=260108 http://www.ct.gov/dot/cwp/view.asp?a=3200&q=260108 http://www.fhwa.dot.gov/bridge/hec21.pdf	HEC-RAS, HEC-2, WSPRO
Delaware	Yes	Refer to HEC 21	http://www.fhwa.dot.gov/bridge/hec21.pdf	
Florida	Yes	Drainage Manual, refer to HEC 21	http://www.dot.state.fl.us/rddesign/dr/files/2010DrainageManual.pdf http://www.fhwa.dot.gov/bridge/hec21.pdf	
Georgia	Yes	Drainage Manual, refers to HEC 21	http://www.dot.ga.gov/doingbusiness/PoliciesManuals/roads/Drainage/Drainage%20Manual.pdf http://www.fhwa.dot.gov/bridge/hec21.pdf	
Hawaii	No			
Idaho	Yes	Design equations are given in Bridge manual, refers to HEC 21	http://itd.idaho.gov/Bridge/manual/manual_April08.pdf http://itd.idaho.gov/bridge/manual/02%20General%20Design%20and%20Location%20Features/A2.1%20Deck%20Drain%20Design%20Procedure.pdf http://www.fhwa.dot.gov/bridge/hec21.pdf	
Illinois	Yes	Refer to HEC 21	http://www.dot.il.gov/bridges/abd032.pdfhttp://www.dot.il.gov/bridges/brmanuals.htmlhttp://www.fhwa.dot.gov/bridge/hec21.pdf	
Indiana	No			
Iowa	No	End Drainage Used	http://www.iowadot.gov/design/dmanual/04c-02.pdf	
Kansas	No			
Kentucky	Yes	Drainage Manual, refer to HEC 21	http://transportation.ky.gov/design/drainage/drainage.html	Hydraflow
Louisiana	Yes	Refer to HEC 21	http://www.dotd.la.gov/highways/project_devel/design/bridge_design/Bridge%20Design%20English%20Manual/08%20Chapter%205%20-%20Superstructure%20Design%20Criteria%20and%20Details.pdf http://www.fhwa.dot.gov/bridge/hec21.pdf	
Maine	Yes	Refer to HEC 21	http://www.maine.gov/mdot/technicalpubs/documents/pdf/hwydg/vol1/chpt12.pdf	
Maryland	Yes	Have guidelines to select the type of scupper to be used	http://www.gishydro.umd.edu/sha_sept07/CH%2012%20%20BRIDGE%20DECKS/CH%2012%20BRIDGE%20DECKS.pdf	Maryland Pavement & Deck Drainage Program (MPADD)
Massachusetts	No			
Michigan	Yes	Refer to HEC 21	http://www.michigan.gov/documents/MDOT_MS4_Chap_91730_7._06_Drainage_Manual.pdf http://www.fhwa.dot.gov/bridge/hec21.pdf	

State	Use Scupper	Design Guidance	Reference Link	Software Used
Minnesota	Yes	Bridge Details Manual, refer to HEC 21	http://www.dot.state.mn.us/bridge/hydraulics/drainagemanual/pdf/chapter%208.pdf http://www.fhwa.dot.gov/bridge/hec21.pdf	
Mississippi	Yes	Refer to HEC 21	http://www.fhwa.dot.gov/bridge/hec21.pdf	
Missouri	Yes	Refer to HEC 21	http://www.fhwa.dot.gov/bridge/hec21.pdf	
Montana	No			
Nebraska	Yes	HEC 12, Urban Drainage Manual	http://www.nebraskatransportation.org/roadway-design/download/draindes-eroscontman.pdfhttp://www.fhwa.dot.gov/bridge/hydpuba.htm#hec	
Nevada	Yes	Refer to HEC 21	http://www.nevadadot.com/reports_pubs/drainage_manual/pdf/drainage_manual2006.pdf http://www.fhwa.dot.gov/bridge/hec21.pdf	
New Hampshire	No			
New Jersey	Yes	Roadway design manual	http://www.state.nj.us/transportation/eng/documents/BDMM/pdf/bmsec22.pdf http://www.state.nj.us/transportation/eng/documents/BDME/	
New Mexico	Yes	Refers to HEC 22, Use Slotted Drains	http://www.nmshtd.state.nm.us/upload/images/drainage_design/NMHydraulicManual.pdf	
New York	Yes	Bridge Manual, refer to HEC 21	https://www.nysdot.gov/divisions/engineering/structures/repository/manuals/brman-usc/Complete_nysdot_US_2010.pdf http://www.fhwa.dot.gov/bridge/hec21.pdf	
North Carolina	Yes	Refer to HEC 21	http://www.ncdot.org/doh/preconstruct/highway/hydro/gl0399web/pdf/guidelines.pdf http://www.fhwa.dot.gov/bridge/hec21.pdf	
North Dakota	Yes	Refer to HEC 21	http://www.dot.nd.gov/manuals/design/designmanual/chapter5/DM-5-02_tag.pdf	HYDRAIN by FHWA
Ohio	Yes	Bridge Design Manual, refer to HEC 22	http://www.dot.state.oh.us/Divisions/HighwayOps/Structures/standard/Bridges/BDM/BDM2007/BDM2007_04-16-10.pdf http://www.dot.state.oh.us/Divisions/HighwayOps/Structures/Hydraulic/LandD/Documents/sec1100bookmarked.pdf http://isddc.dot.gov/OLPFiles/FHWA/010593.pdf	ODOT CDSS
Oklahoma	Yes	Refer to HEC 21	http://www.fhwa.dot.gov/bridge/hec21.pdf	
Oregon	Yes	Details not given in the drainage manual	ftp://ftp.odot.state.or.us/techserv/Geo-Environmental/Hydraulics/Hydraulics%20Manual/	
Pennsylvania	Yes		ftp://ftp.dot.state.pa.us/public/bureaus/design/PUB584/PDMChapter10.pdf	
Rhode Island	No			
South Carolina	Yes	Bridge Design Manual	http://www.scdot.org/doing/bridge/pdfs/BD_manual/Files/Chapter_18.pdf	DRAIN
South Dakota	No			
Tennessee	No	End Drainage Used	http://www.tdot.state.tn.us/chief_engineer/assistant_engineer_design/design/DrainManpdf/Chapter%207.pdf	
Texas	Yes	Hydraulic design manual, Use Slotted Drains	http://onlinemanuals.txdot.gov/txdotmanuals/hyd/hyd.pdf	
Utah	No	Refer to AASHTO, Highway Drainage Guidelines, Chapter 9 (2), and HEC 21 (4) and HEC 22 (9).	http://www.udot.utah.gov/main/uconowner.gf?n=200403161048103 http://www.fhwa.dot.gov/bridge/hec21.pdf	
Vermont	No			

State	Use Scupper	Design Guidance	Reference Link	Software Used
Virginia	Yes	Equations given	http://www.extranet.vdot.state.va.us/locdes/electronic%20pubs/2002%20Drainage%20Manual/pdf/drain-manual-chapter-09.pdf	
Washington	No	Use End drainage system		
West Virginia	Yes	Refer to HEC 21	http://www.transportation.wv.gov/highways/engineering/Manuals/Drainage/WVDOH_2007_Drainage_Manual.pdf http://www.fhwa.dot.gov/bridge/hec21.pdf	
Wisconsin	Yes	Refer to HEC 21	http://www.fhwa.dot.gov/bridge/hec21.pdf	
Wyoming	No			

Chapter 3. Physical Model

The physical model study was held in the Center for Research in Water Resources (CRWR) laboratory at the J. J. Pickle Research Campus of The University of Texas at Austin. The facility was constructed to study and evaluate the performance of recessed curb inlets, flush dressed curb inlets, various bridge deck drains, and drainage of highways at super elevation transitions (Holley et al. 1992; Hammons and Holley 1995; Smith and Holley 1995; Charbeneau, Jeong, and Barrett 2008).

3.1 Model Construction

The model was constructed in two phases: the steel structure in which the bridge decking would sit, and the bridge decking. The steel structure was designed to allow no more than 1/8 in. deflection at any part of the structure (Holley et al. 1992). The model deck is supported by two steel frames with top beam and two columns as shown in Figures 3-1 and 3-2. At the upstream, two five-ton crane hoists are attached between the top steel beam and the W12×16 steel lifting beam (Figure 3-1). At the downstream, only one chain hoist is attached to the top beam and the lifting beam. A ball bearing with seats supports the other end of the downstream lifting beam (Figure 3-2). The lifting beams supports two longitudinal 60-ft W18×35 steel beams. A series of 2in. × 6in. wood joists were assembled above and perpendicular to the longitudinal beams. Sheets of plywood are placed on the top of these wood joists. The plywood provides a base for the deck surface. Two curbs were constructed out of wood and reinforced with angle iron on the outside for the full length of the model. The model was built at full scale for a one-lane bridge deck with drains.

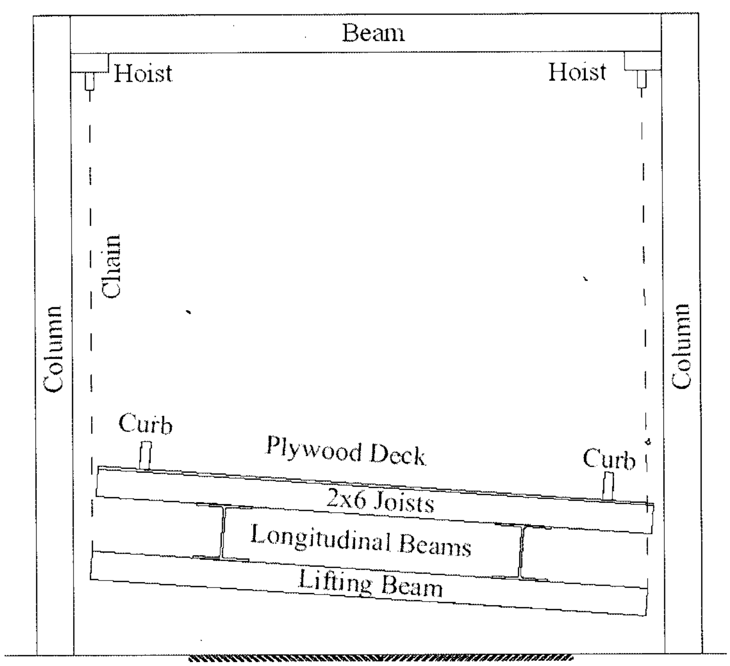

Figure 3-1 Upstream Support Cross-Section

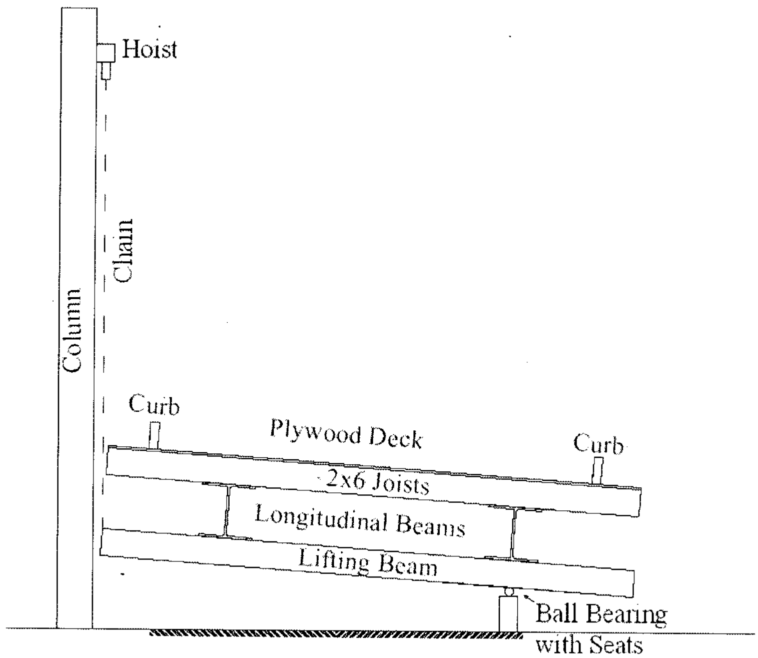

Figure 3-2 Downstream Support Cross-Section

3.2 Model Layout

The model deck's surface dimensions measured 10.5 feet (3.2 meters) wide and 64 feet (19.4 meters) long as shown in Figure 3-3. The head box was constructed at the most upstream position. Two water pumps supplied the water from a half-million gallon reservoir located just outside of the laboratory. The head box spanned the full width of the bridge and 5 feet (1.52 meters) in length downstream. The 2-in. high water outlet is located at the base of the front face of the head box and discharges directly onto the bridge surface. Concrete cinder blocks were placed against the downstream wall inside the head box to reduce turbulence. Five drains were constructed in series with a spacing of 18 inches from nose to nose. The distance from the head box to the upstream drain station is 46.6 feet. Along the length of the decking, 14 measurement stations were designated to gather water profile and depth measurements.

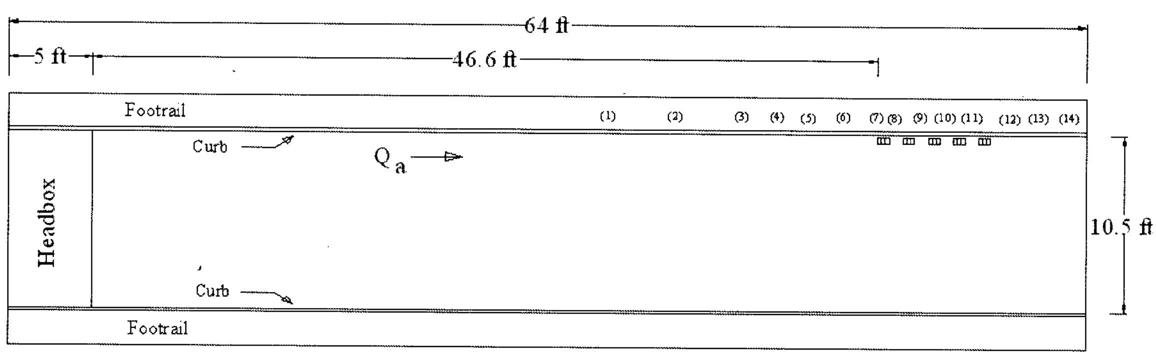

Figure 3-3 Model Layout

3.3 Bridge Deck Drain

Five 4in. × 8in. drains were placed in series along the left edge (looking downstream) with the first drain 46.6 feet (14.2 meters) away from the downstream wall of the head box. The drains were spaced 10 inches from each other and 1 inch from the curb as shown in Figure 3-4. The 4in. side of the drain was positioned perpendicular to the upstream flow direction.

Figure 3-4 Plexiglas Drain Installments along Model Roadway

The drains were installed flush with the surface of the deck. They were constructed out of Plexiglas to simulate the prototype built from steel with the basic outer dimensions of 4in. × 8in. × 6in. Four flanges were attached on the drain; two of them were to secure the drain to the deck and the other two were to secure the drain cap and rubber gasket (see Figure 3-5). Following the designed experiments for the 4in. × 8in. drains, all five drains were removed. Each opening in the deck was cut 2 inches wider in order to place 6in. × 8in. drains for use with further experiments.

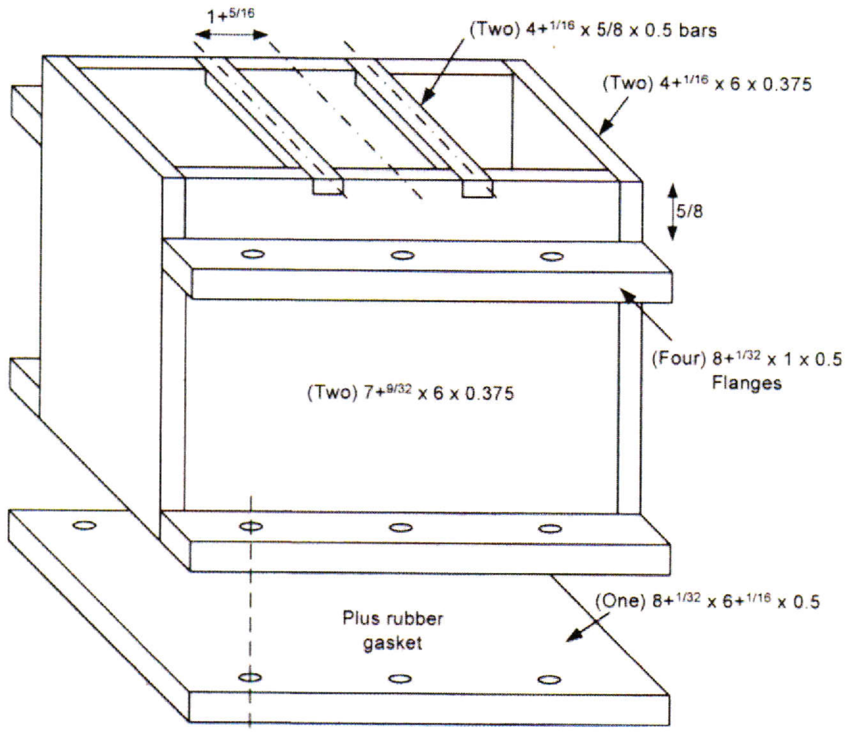

Figure 3-5 Scaled Drawing of Model Plexiglas Deck Drain

3.4 Measurements

Water discharges from the decking surface into two separate reservoirs: one for the capture discharge and one for the bypass discharge. Each reservoir has a V-notch weir for measurement of discharge from the reservoir. Discharge from the reservoirs is routed back to the main storage reservoir located outside of the laboratory.

The head at the capture and bypass weirs was measured to determine the corresponding discharges. Measurements were taken for a series of water spread and water depth locations along the bridge deck.

3.4.1 Discharges

The water captured by the drains was fed via free fall to a small reservoir by a box slide as shown in Figure 3-6. The box slide dimensions extended farther upstream from the first drain and were 1 foot wider on either side of the drains. The box slide did not limit the captured discharge. The slide was supported by the cross beam of the model structure and the wall of the 'captured' reservoir. Exact position of the slide varied as the cross and longitudinal slopes changed. The flow rate of the captured water was measured by a V-notch weir located at the end of the reservoir.

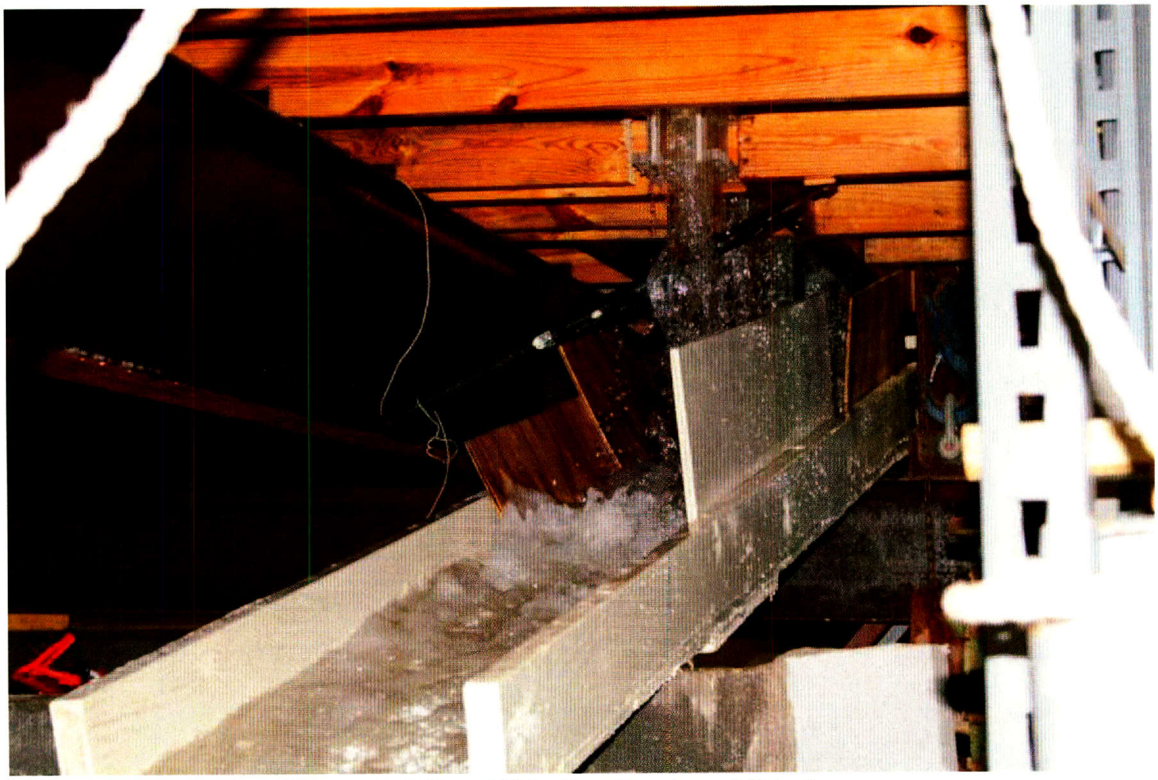

Figure 3-6 Box Slide for Captured Discharge

The water bypassed by the drains flowed to a tail box located at the end of the deck. From here, the water was fed in the 'bypassed' reservoir by another box slide and a 6in. diameter corrugated plastic tube as shown in Figure 3-7. This box slide was harnessed to the tail box with cables and hooks at the upstream portion of the slide and was supported on the wall of the reservoir. The tubing fed the water straight into the reservoir. The bypass discharge was measured at the end of the reservoir by a V-notch weir. Both 60 and 120 degree weirs were used to determine the discharges. The 120 degree weirs were used for the larger discharges while the 60 degree weirs were used for the smaller discharges.

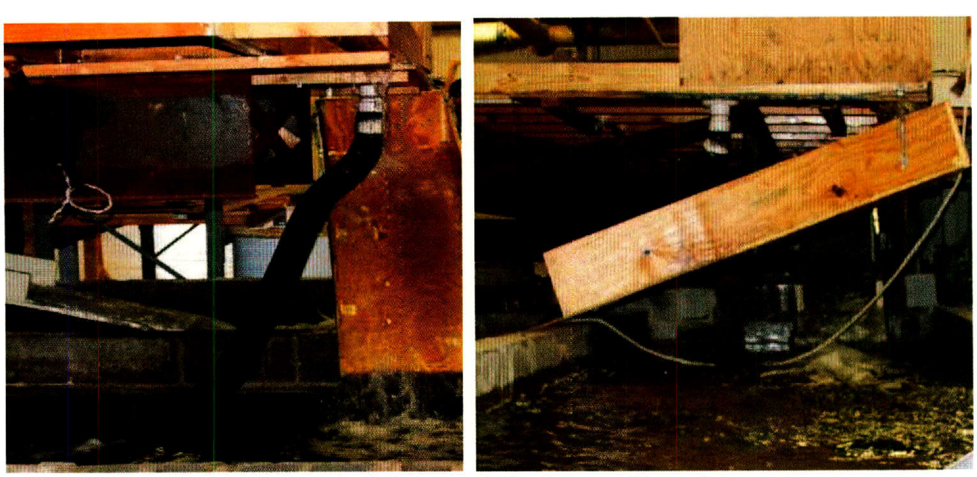

Figure 3-7 Bypass Discharge Routing

3.4.2 Water Profile

Water depth measurements were taken at 16, 12, 8, 6, 4, 2, and 0 feet upstream of drain 1 (labeled 1, 2, 3, 4, 5, 6, and 7 in Figure 3-3) and between drains 1 and 2, drains 2 and 3, drains 3 and 4, and drains 4 and 5 (labeled 8, 9, 10, and 11 in Figure 3-3). Measurements were also taken at locations 9, 6, and 3 feet upstream from the end of the deck surface (labeled 12, 13, and 14 in Figure 3-3). Water spread and curb depth measurements were taken at all stations as "water depth measurements."

3.5 Model Modification and Repair

Two small problems occurred in the early runs of the experiments: splash in the capture slide and turbulence of the water surface in the diverted reservoir for collecting capture discharge created uncertainty in measured values. The capture slide was designed to be able to move with the adjustments of slope and fit between the bridge decking and the beam, so it was rather shallow in depth (about 5 inches). The water discharged from the drains into the slide would splash out of the slide and therefore would not be delivered to the capture reservoir. A simple modification was made to increase the height of the slide walls of the capture slide. Vice grips were used to attach the wood to the slide wall and allowed easy adjustment of the drains, as shown in the top of Figure 3-8.

Figure 3-8 Modifications to Capture Box Slide

The second issue was that the captured flow discharged from the slide to the reservoir with high velocity, which caused fluctuation on the water surface. Gaining an accurate weir measurement was difficult. To reduce the flow velocity flowing into the capture discharge reservoir, a foot board was added at the downstream end of the slide as shown in Figure 3-8. The water would strike the foot board and be directed away from the weir in the reservoir. This resulted in a more accurate reading head on the weir.

3.6 Physical Model Procedures

The experimental procedure was designed to obtain the data required for analysis while maintaining the data's accuracy. The cross slope of the model bridge was set to vary from 2% to 6% with longitudinal slopes from 0.1% to 4%. The approach discharge varied from 0.0 to 2.0 cfs. Two drain sizes of 4in. × 8in. and 6in. × 8in. were tested. The drains were tested in series, with up to five drains open at one time. The drains were placed with centerline spacing of 18 inches. The experiment design series is shown in Table 3-1 in Section 3.8.

3.6.1 Experimental Procedure Modifications

At the beginning of the experiment, the team waited for 30 to 60 minutes after each run. This time lapse allowed the discharge to balance on the bridge deck and through the capture and bypass reservoirs. Based on double-checking of measured discharges, the team was able to reduce the amount of time after runs to 15 minutes. This reduction in waiting time held for every run but the initial run of the day and also for runs with very small approach discharge. The limiting factor was the bypass weir, as the bypass reservoir was about twice the volume as the capture reservoir. The team also noticed the discharge balanced faster at higher approach discharges.

3.6.2 Experiment Setup

1. Open pipe valve fully to provide water from outdoor reservoir to head box.
2. Turn the turbine pump switch to 'manual' on the control box.
3. Remove or install base plates for the drains for the corresponding run taking place.
4. Adjust the pulley heights for the particular cross and longitudinal slopes.

3.6.3 Experiment Procedure

1. Open the valve at the head box by turning one full revolution.
2. Wait at least 30 minutes for the capture and overflow weir levels to balance. Record the capture and overflow weir heights.
3. Wait another 5 minutes and record weir heights again. If the two measurements are not equal to their respective counterparts, repeat this step until two consecutive equal measurements are recorded.
4. Once equal, record water depth and spread at each required location.
5. Increase the valve position by one-quarter revolution.
6. Repeat steps 2–4 until the head in the overflow weir reads at least 0.5 feet. Note: Only 15 minutes may be needed for step 2 after the initial run for a particular setup. If two pumps are required to produce 0.5 feet of head in the overflow weir, follow 'Experiment Set Up' for the second pump and continue to increase the head box valve as needed.

3.6.4 Experiment Shutdown

1. Close valve at head box.
2. Turn vertical, turbine pump switch to 'off'.
3. Close pipe value at the junction near the pump switch and control box.

3.7 Discharge Measurement from V-Notch Weirs

Using the two V-notch weirs at the bypass and capture reservoirs, the discharges can be calculated with the following equation.

$$Q = C_e \frac{8}{15}\sqrt{2g}\tan\left(\frac{\theta}{2}\right)H^{2.5} \tag{3.1}$$

where Q = discharge (cfs)

C_e = 0.584 for a 120 degree weir; 0.590 for a 60 degree weir

θ = angle of the V-notch weir (degrees)

H = measured head on weir (ft)

Using these coefficients, Equation 3.1 becomes

$$Q = 4.33\,H^{2.5} \quad \text{(120 degree weir)} \tag{3.2}$$

$$Q = 1.46\,H^{2.5} \quad \text{(60 degree weir)} \tag{3.3}$$

3.8 Physical Model Design

Two drain sizes, 4in. × 8in. and 6in. × 8in., have been modeled in the lab. Six physical model series of experiments are listed in Table 3-1. Each run tested for a combination of 1 drain to 5 open drains at 5 to 10 different approach discharges. The total number of the tests to be performed for the 4in. × 8in. drain is the product of the number of drains (5) × cross slopes (3) × longitudinal grades (5) × flow rates (5 to 10) = 375 to 750. The total number of the tests to be performed for the 6in. × 8in. drain is the product of the number of the drains (5) × cross slopes (3) × longitudinal grades (2) × flow rates (5 to 10) = 150 to 300. Each test was logged into a sheet shown in Figure 3-9.

Table 3-1 Experiment Series

Run	Drain size	Longitudinal Slope	Cross Slope
1.	4″ × 8″	0.1%, 0.5%,1%, 2%, and 4%	2%
2.	4″ × 8″	0.1%, 0.5%,1%, 2%, and 4%	4%
3.	4″ × 8″	0.1%, 0.5%,1%, 2%, and 4%	6%
4.	6″ × 8″	0.5% and 2%	2%
5.	6″ × 8″	0.5% and 2%	4%
6.	6″ × 8″	0.5% and 2%	6%

Date					
Name					
Slope		% (cross)		% (longitudinal)	
Flowrate (revolution)	1	1.25	1.5	1.75	2
# of open drain	1	2	3	4	5

	Height of water (ft)	Height of water (ft)	Height of water (ft)	
Time				
Capture weir				
Overflow weir				

	Height of water (ft)	Spread of water (inch)
Station 1 (16 feet from drain 1)		
Station 2 (12 feet from drain 1)		
Station 3 (8 feet from drain 1)		
Station 4 (6 feet from drain 1)		
Station 5 (4 feet from drain 1)		
Station 6 (2 feet from drain 1)		
Station 7 (0 feet from drain 1)		
Station 8 (drain 1 & 2)		
Station 9 (drain 2 & 3)		
Station 10 (drain 3 & 4)		
Station 11 (drain 4 & 5)		
Station 12 (9 feet from the end)	-	
Station 13 (6 feet from the end)	-	
Station 14 (3 feet from the end)	-	

	Elevation
Pulley 2	
Pulley 3	
Pulley 4	

Figure 3-9 Measurement Log for Each Run

Chapter 4. Experimental Results

The experimental data from this study were tabulated in a database and listed in Appendix A. A total of 822 tests were completed. Of this total, 586 tests were for the 4in. × 8in. drains, and 236 tests were for the 6in. × 8in. drains. The principal variables are the capture discharge (Q_c), approach discharge (Q_a), flow curb depth (Y) of the approach discharge, the number of the drains (N), cross slope (S_x) and longitudinal slope (S_0) of the bridge deck, drain length (L), and drain width (W). The capture discharge is calculated from Equation 3.2 or 3.3 and the approach discharge is the sum of the capture discharge and bypass discharge. The cross slope was calculated by dividing the average ponding width by the curb depth.

4.1 Comparison with Previous Studies

To compare the experimental data for the new rectangular deck drains with previous studies, the relationship between the measured capture discharge and the approach curb water depth for a single drain open has been plotted in Figure 4-1 for a series of runs with different cross slopes. In Figure 4-1, the maximum water depth is 0.29 feet, which is higher than the break point water depth in Figure 2-8 (0.1 feet), and the maximum discharge is 0.261 cfs, which is over 0.16 cfs break point in Figure 2-9. No break point is obvious in the slope, as suggested by the possibility of transition from weir-type flow to orifice-type flow at greater flow depths. This set of runs might have yielded this result because the higher hydraulic performance of the new drain does not cause the orifice-type behavior. The orifice-type behavior was observed once the approach discharge was spread across more than one lane, which has no practical meaning. In addition, the effect of the different longitudinal and cross slopes is not as significant as indicated in previous studies. The weir equation $Q_c = 3.24(\frac{2y}{3})^{1.5}$ can fit the experiment data with coefficient of determination R^2 =0.9871 and root mean square error = 0.0145.

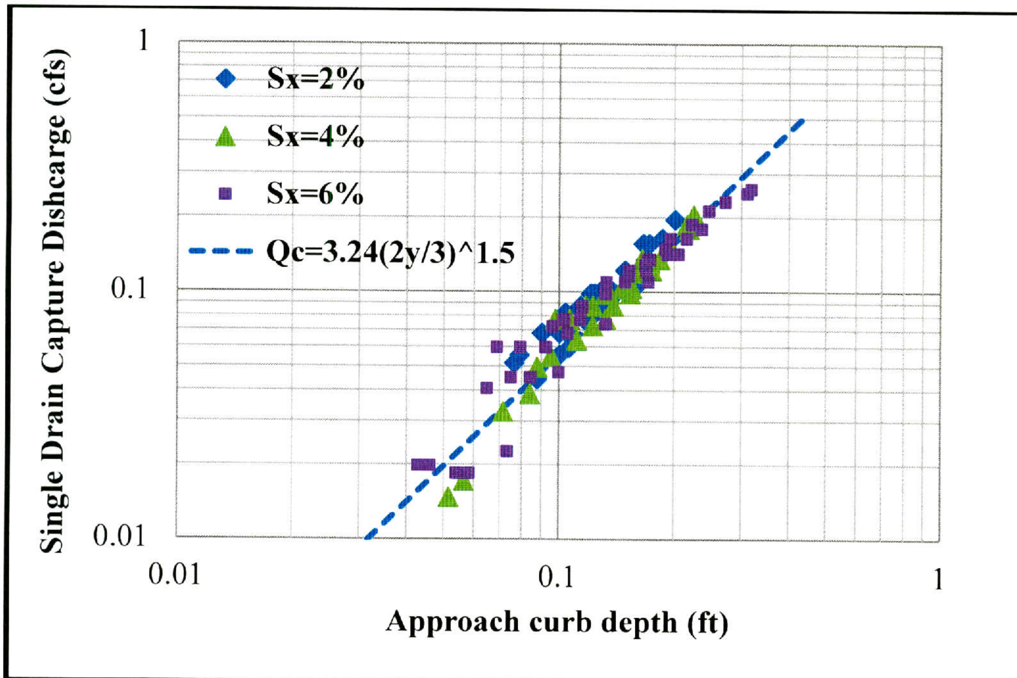

Figure 4-1 Capture Discharge for a Single Drain vs. Approach Curb Depth at Different Longitudinal and Cross Slopes

4.2 Bridge Deck Roughness Coefficient

The plywood surface was made to simulate a bridge deck surface. Fine grain sand was poured onto the plywood and distributed evenly. Polyurethane coats were applied on top of the sand, which aided in distributing the sand evenly across the deck surface.

The Manning's roughness coefficient for the model should correspond to a typical bridge with Manning coefficient in the range 0.011 to 0.017 (Brown et al. 2009).

The Manning coefficient was determined by experimentation with all drains closed. Each experimental run had different cross and longitudinal slopes. The cross slopes were S_x = 2, 4, and 6%. The longitudinal slopes were S_0 = 0.1, 0.5, 1, 2, and 4%. Five incremental flow rates were used for each slope combination. Measurements were taken for the water depth, water spread, and discharge from the bypass weir. The station locations for the water depth and spread measurements were the same as listed in Section 3.2. Manning's *n* can be calculated using Izzard's equation (Equation 2.1). Manning's roughness coefficient was also calculated for each variant of longitudinal slope as shown in Figure 4-2. The blue, red, and green dotted lines are the results for cross slope S_x = 2%, S_x = 4%, and S_x = 6%, respectively. Each point on each curve gives the average from five different flow rates. The thick red line is the averaged Manning's coefficent for three different cross slopes at five different longitudinal slopes. The Manning's coefficient for 0.1% longitudinal slope is significantly different from that for all other slope values. The average Manning's coefficient value for the 0.1% longitudinal slope is n = 0.0122; however, the averaged value of *n* for the 0.5%, 1%, 2%, and 4% longitudinal slope is close to 0.0166.

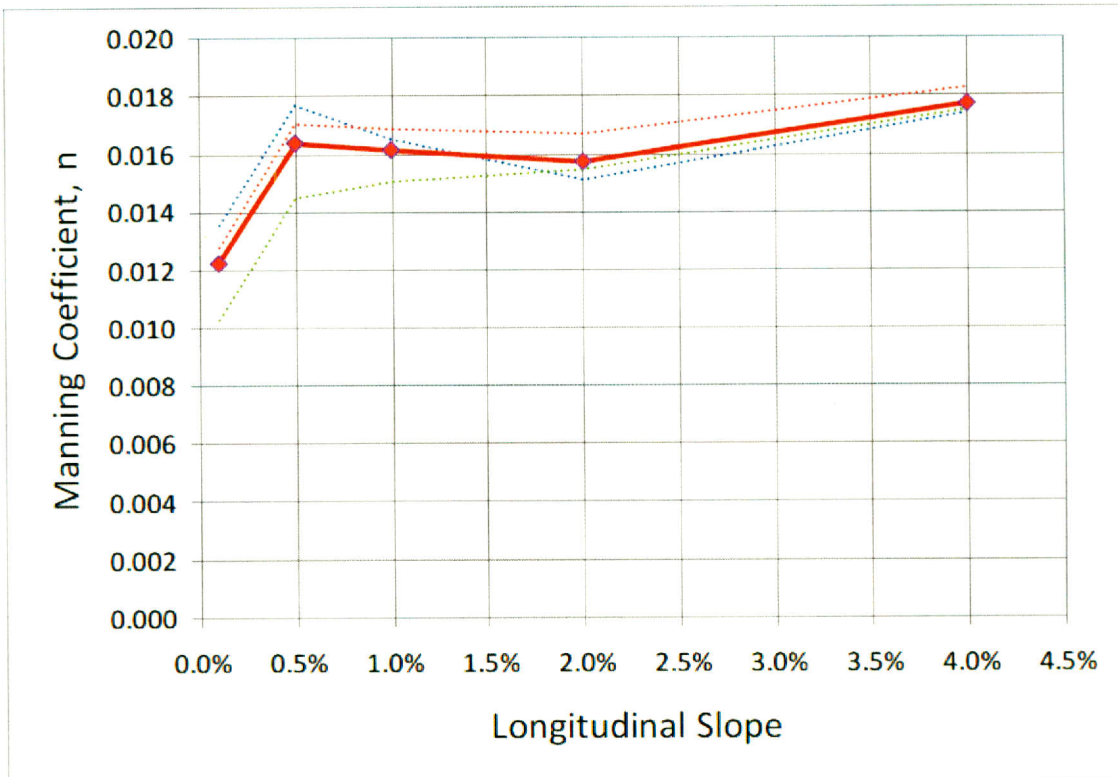

Figure 4-2 Manning's Roughness Coefficient as a Function of Longitudinal Slope, Averaged Cross Slope S_x = 2% (Blue Dotted Line), 4% (Red Dotted Line), 6% (Green Dotted Line), and Average Cross Slope (Solid Red Line) with Discharge Settings Q = 1.0, 1.25, 1.5, 1.75, and 2.0 Revolutions at the Head Box Control Valve for Each Slope Combination

Manning's *n* is estimated through minimizing the root-mean square difference between the discharges in Equation 3.2 and Equation 2.1. Figure 4-3 shows the results for the estimation of Manning's *n*. The longitudinal slope of 0.1% was not included in this analysis as the estimated *n* was significantly different. The resulting Manning's coefficient (n = 0.0164) correlates to the entire range of the experiment except S_0 = 0.1%.

Figure 4-3 illustrates the consistency of Manning's roughness coefficient from the comparison of the measured discharge to the calculated discharge from Izzard's equation. The measured discharge values were taken from the weir. In determining the calculated discharge, the range of experiments with cross slopes of 2, 4, and 6% and longitudinal slopes of 0.5, 1, 2, and 4% were used in Izzard's Equation. The water spread used in the equation was an average of spread measured at stations 3, 4, 5, and 6 in Figure 3-3.

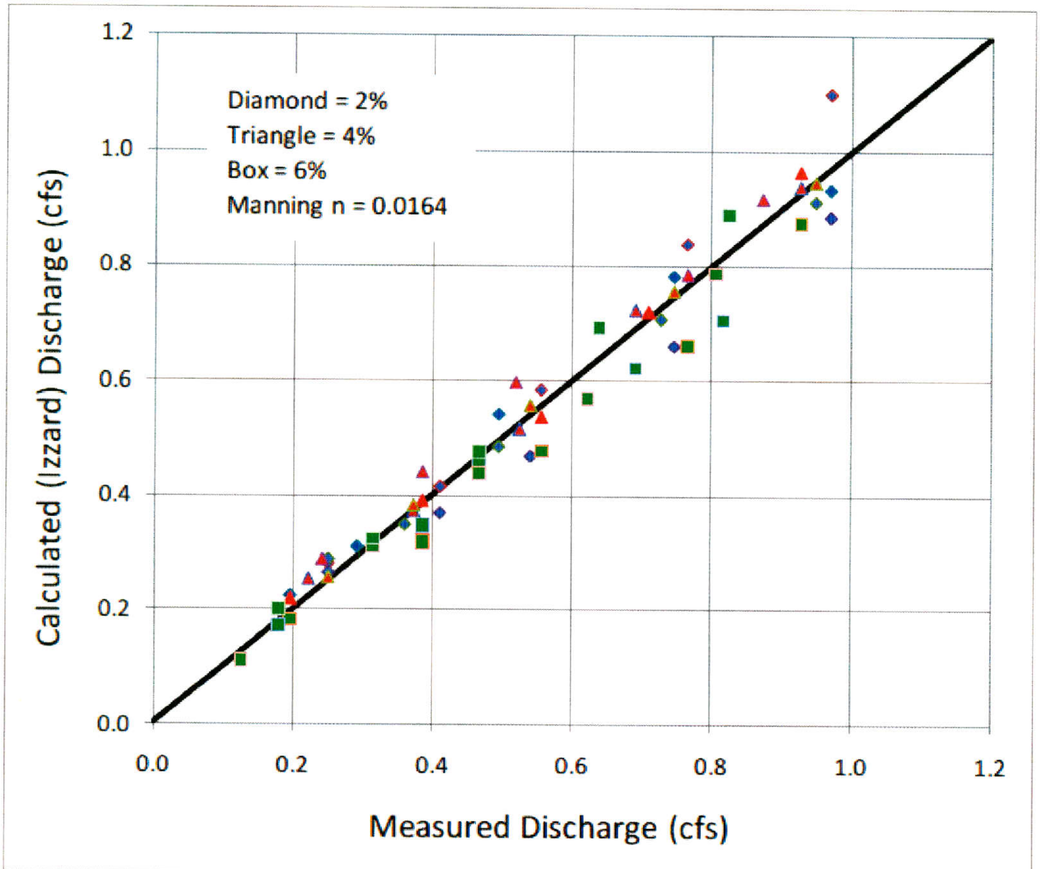

Figure 4-3 "Best Fit" Manning's Roughness Coefficient

4.3 Slotted Drain Method from the FHWA

The adapted slotted drain FHWA method computes the length of slotted inlets (with slot widths ≥1.75 inches) required for total interception flow using the same equation as curb-opening inlets (Brown et al. 2009) as previously described in Equation 2.18. To evaluate the applicability of the equations for slotted drains in predicting the hydraulic performance of rectangular deck drains, Equation 2.18 was used to estimate the maximum capacity of the drain with no carryover discharge. The capture discharges were calculated assuming the length of drain inlet is equal to the total length of the open drains, i.e., $L_T = N \times 0.667$ft, where N is the number of open drains. The comparisons were made between the theoretical calculation and experimental measurements for 4in. × 8in. drains. Since the slotted drain method was developed for the maximum capture discharges without carryover discharge, the data from the experiment does not truly satisfy this condition. Therefore, the data without carryover discharge, but having the maximum capture discharge, and the data with less than 1% carryover discharge were selected for the comparison. Figure 4-4 shows the ratios between measured to calculated capture discharge using the slotted drain method. The ratios vary from 1.21 to 17.

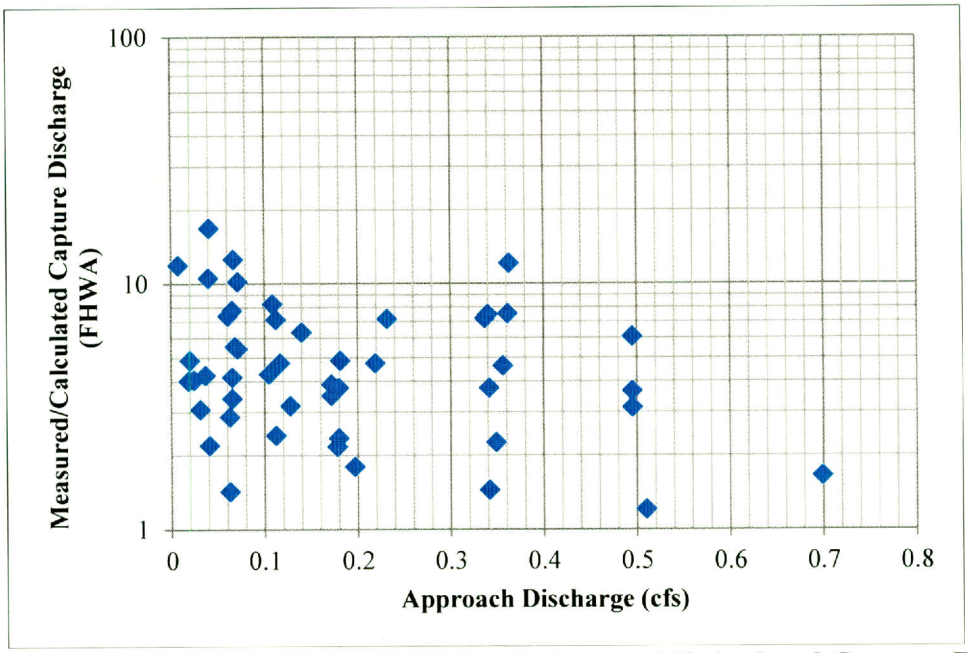

Figure 4-4 The Approach Discharge vs. Ratio of Measured/Calculated Capture Discharges Using Slotted Drain Method

The slotted drain method underestimates the capacity of 4in. × 8in. rectangular deck drain as the ratios are greater than 1 for all the cases examined. The ratios could be considered as a correction factor for the rectangular deck drain to the slotted drain methods being adopted. Given the wide range of the correction factors, further data analysis is needed to identify the influential variables affecting the correction factor and to establish a quantitative relationship between them. In addition to cross slope (S_x), longitudinal slope (S_0), and approach discharge (Q_a), a unique variable for the rectangular deck drain—the width of the drain (W)—should also be considered in establishing the correction factor equation. This factor was not included in the slotted drain methods but significantly affects the capacity of the rectangular deck drains. However, the experimental data clearly demonstrated that 6in. x 8in. drains have higher capacity than 4in. × 8in. drains. Therefore, the width of the drain (W) is also a critical variable of the hydraulic performance of the rectangular drain. Rather than pursue application of a slotted drain correction factor, an alternative approach was taken based on development of a new equation specifically for rectangular deck drains.

4.4 Preliminary Data Analysis and Equation Development

The weir-type behavior has been noted in previous studies and the current study. During some runs, a red dye was introduced into the approach discharge to show the flow path into the drain opening. The dye tests revealed both frontal and lateral flow into the drains have weir-like flow characteristics. The current data for a single drain open can be modeled with a weir equation. The data also show that each drain performs very similarly for 4in. × 8in. and 6 in. × 8 in., although the bigger drain width increases the hydraulic performance. Therefore, the capture discharge from a set of N drains is expressed in Equation 4.1.

$$Q_c = cN\sqrt{g}\left(\frac{2y}{3}\right)^{1.5}(L+W) \qquad (4.1)$$

The coefficient c is the function of the cross slope and longitudinal slope and is expressed as (Holley et al. 1992; Brown et al. 2009)

$$c = aS_0^{\alpha} S_x^{\beta} \qquad (4.2)$$

where c = coefficient
L = drain length (ft)
W = drain width (ft)
y = curb depth calculated from Izzard's equation (ft)

Combining Equation 4.1 with Izzard's equation (Equation 2.1) with g = 32.2 ft/s ^{2} allows Equation 4.1 to be expressed as

$$Q_c = c4.292N\left(\frac{nQ_a S_x}{\sqrt{S_0}}\right)^{9/16}(L+W) \qquad (4.3)$$

If $Q_c > Q_a$, the model assumes no bypass discharge, i.e., $Q_c = Q_a$. Using the regression method in Microsoft Excel 2007, a, α, and β can be estimated from the data. The fitted c and statistical measurements are listed in Table 4-1 for different drain sizes.

Table 4-1 Fitted Coefficients in Equation 4.3 and Statistical Analysis Results

Drain	4″ × 8″	6″ × 8″	Both Drains
a	0.3602	0.5469	0.3989
α	0.1043	0.1205	0.1043
β	-0.2816	-0.1760	-0.2503
R^2	0.9532	0.9760	0.9328
Standard Error	0.0403	0.0242	0.0429

Equation 4.3 indicates that the coefficient c increases with the increased longitudinal slopes but decreases with the increased cross slopes. By substituting the coefficients for both drains (column 4 in Table 4-1) in Equation 4.3 and combining with Equation 4.2, the relationship between the approach discharge and capture discharge can be expressed in Equation 4.4:

$$Q_c = 1.712N(nQ_a)^{9/16}(L+W)\frac{S_x^{0.3122}}{S_0^{0.1770}} \qquad (4.4)$$

Again, if $Q_a < Q_c$ in Equation 4.4, there is no bypass discharge and $Q_c = Q_a$ (100% efficiency). By substituting $Q_a = Q_c$ in Equation 4.4, the 100% efficiency capture discharge can be expressed in Equation 4.5:

$$Q_{c100\%} = 3.4176(N\ (L+W))^{16/7} n^{9/7} \frac{S_x^{0.7136}}{S_0^{0.4046}} \qquad (4.5)$$

Equation 4.4 assumes the hydraulic performance is the same for each drain and the capture discharge is proportional to the sum of the drain length and width. Note that the Manning's *n* was calibrated from the experiments with n = 0.016 for $S_0 \geq 0.005$, and n = 0.012 for $S_0 = 0.001$. With n = 0.016 applied for $S_0 = 0.001$ in Equation 4.4, the captured flow rate will increase 11.4% over n = 0.012.

The captured discharge (dashed lines), calculated from Equation 4.4, and the measured capture discharge for the 4in. × 8in. drains versus the approach discharge is plotted in Figures 4-5, 4-6, and 4-7 for N=1 (solid blue diamond), N=2 (solid red rectangle), N=3 (solid green triangle), N=4 (open diamond), and N= 5 (open triangle). These figures show the capture discharge increases as the longitudinal slope decreases.

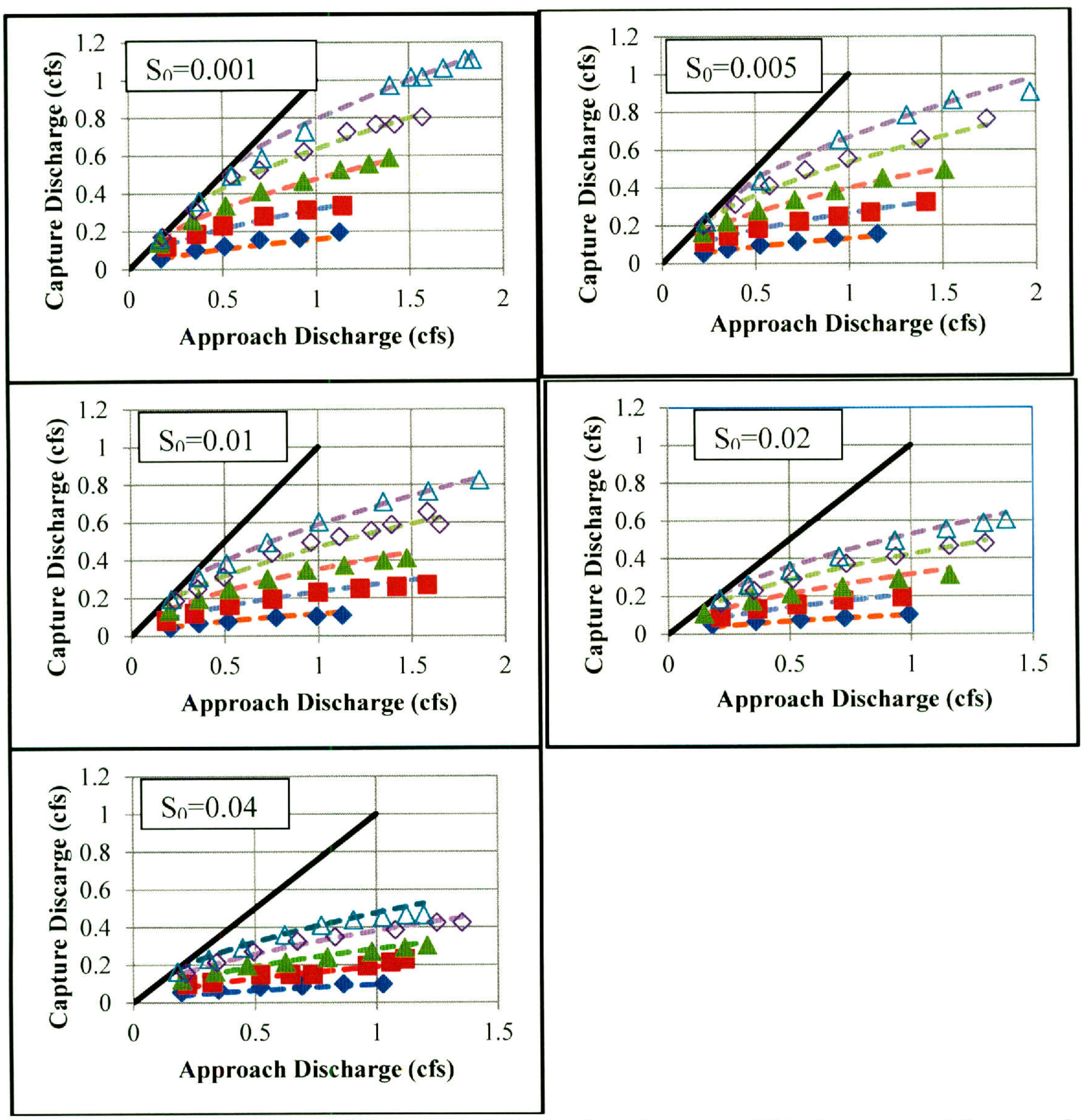

Figure 4-5 Comparison of Developed Equation Captured Discharge vs. Measured Capture Discharge for 2% Cross Slope and Five Longitudinal Slopes for 4in. × 8in. Drain

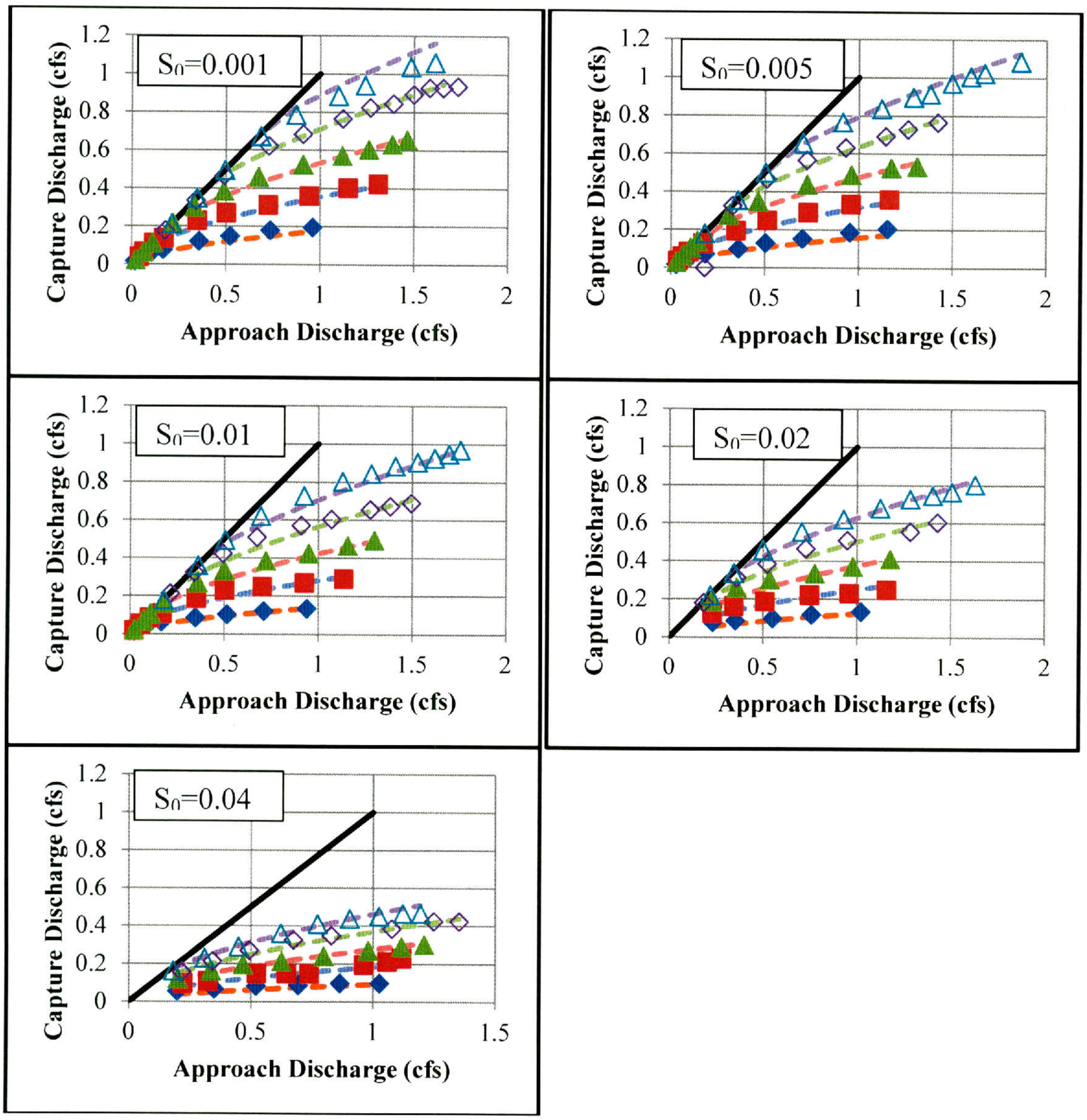

Figure 4-6 Comparison of Developed Equation Captured Discharge vs. Measured Capture Discharge for 4% Cross Slope and Five Longitudinal Slopes for 4in. × 8in. Drain

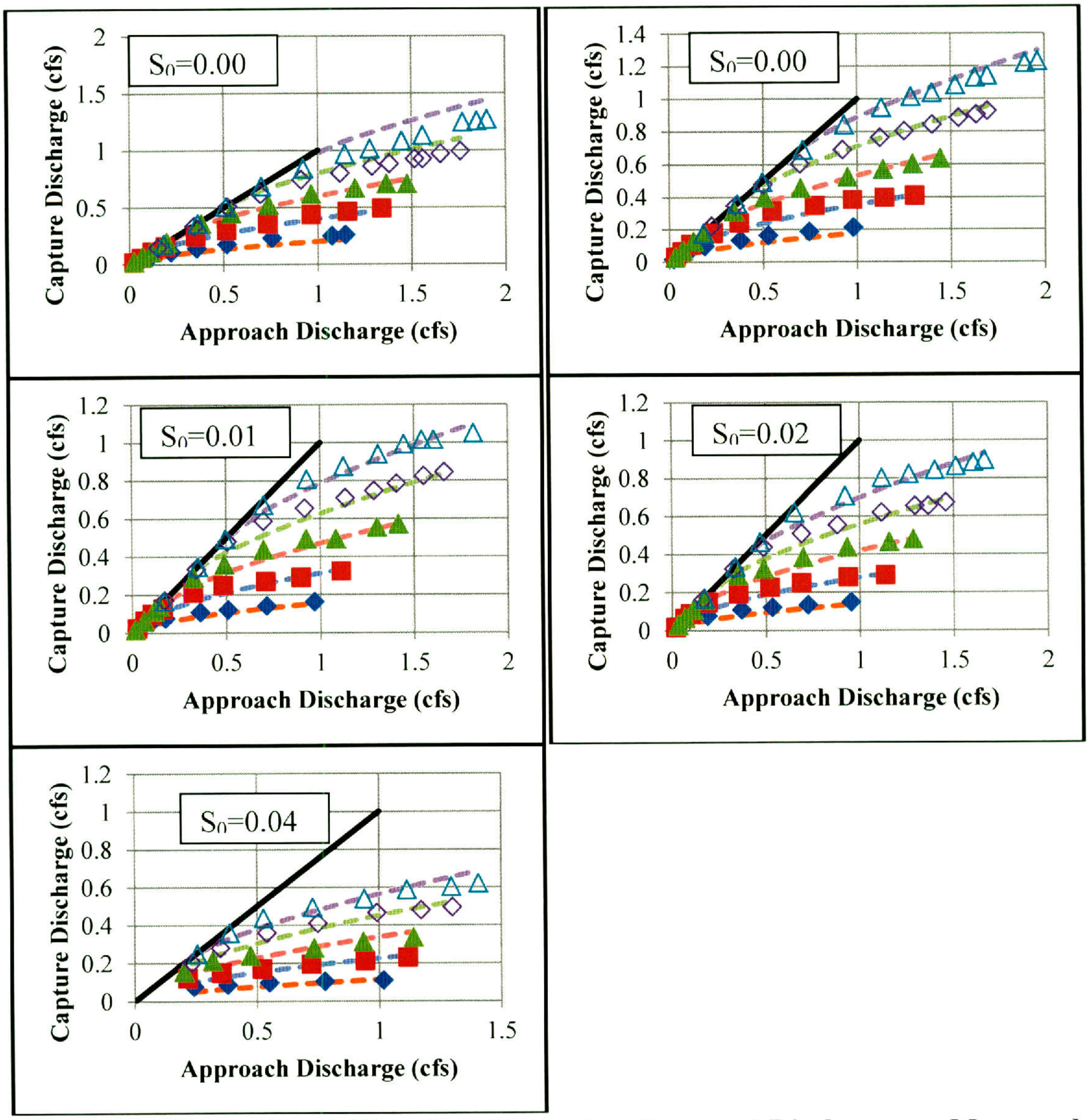

Figure 4-7 Comparison of Developed Equation Captured Discharge vs. Measured Capture Discharge for 6% Cross Slope and Five Longitudinal Slopes for 4in. × 8in. Drain

Figures 4-8, 4-9, and 4-10 compared the model prediction and the experiment data for the 6in. × 8in. drains. In Figures 4-8 and 4-10, it can be noted that the hydraulic performance is overestimated for five open drains when the hydraulic performance fits data very well for one-drain or two-drains open. However, the hydraulic performance is underestimated for one-drain open when it fits data very well for five open drains as in Figure 4-9. Therefore, the hydraulic performance of the larger drain size appears to decrease in efficiency with increasing number of drains open. However, the difference in performance is not significant.

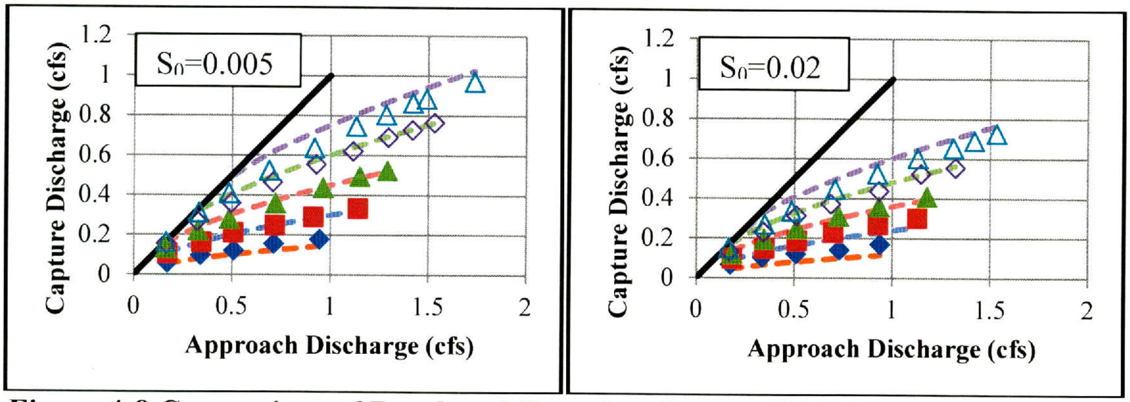

Figure 4-8 Comparison of Developed Equation Captured Discharge vs. Measured Capture Discharge for 2% Cross Slope and Two Longitudinal Slopes for 6in. × 8in. Drain

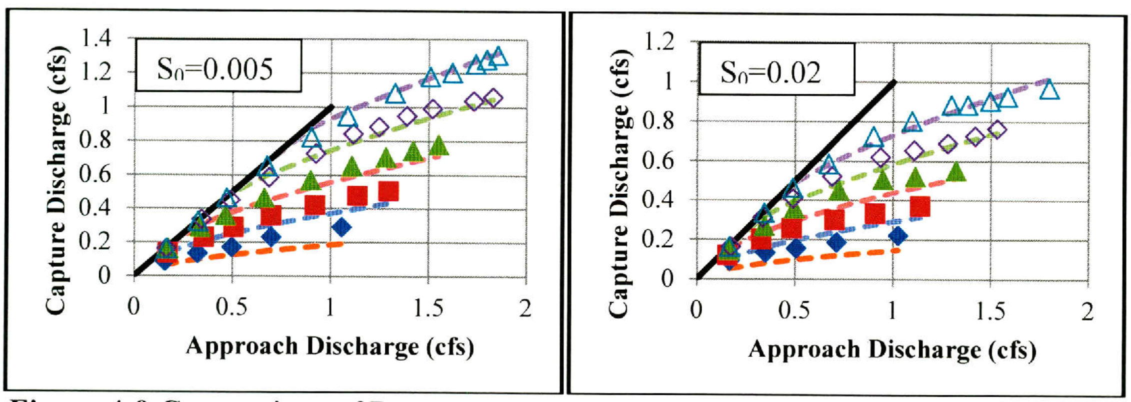

Figure 4-9 Comparison of Developed Equation Captured Discharge vs. Measured Capture Discharge for 4% Cross Slope and Two Longitudinal Slopes for 6in. × 8in. Drain

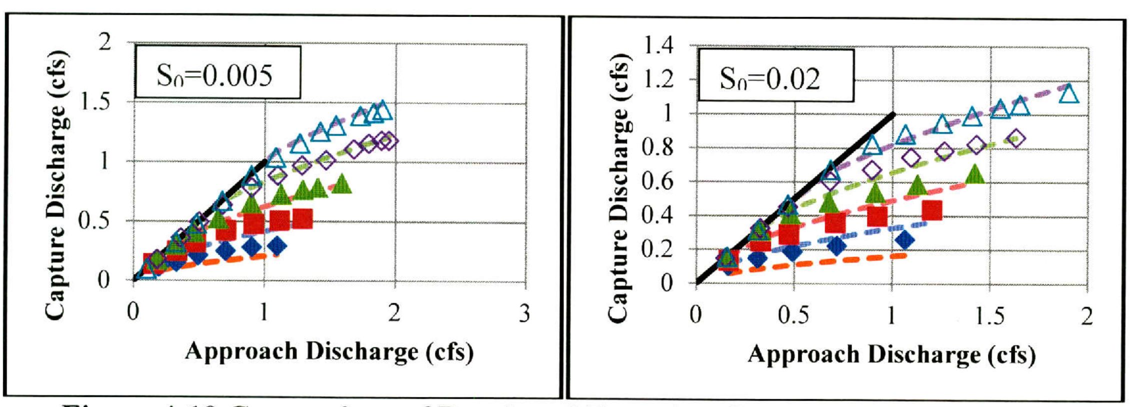

Figure 4-10 Comparison of Developed Equation Captured Discharge vs. Measured Capture Discharge for 6% Cross Slope and Two Longitudinal Slopes for 6in. × 8in. Drain

The captured discharge calculated by Equation 4.4 and the measured capture discharge are compared for all the data in Figure 4-11. This figure demonstrates that the model has high agreement with the measurements (statistical results are shown in Table 4-1).

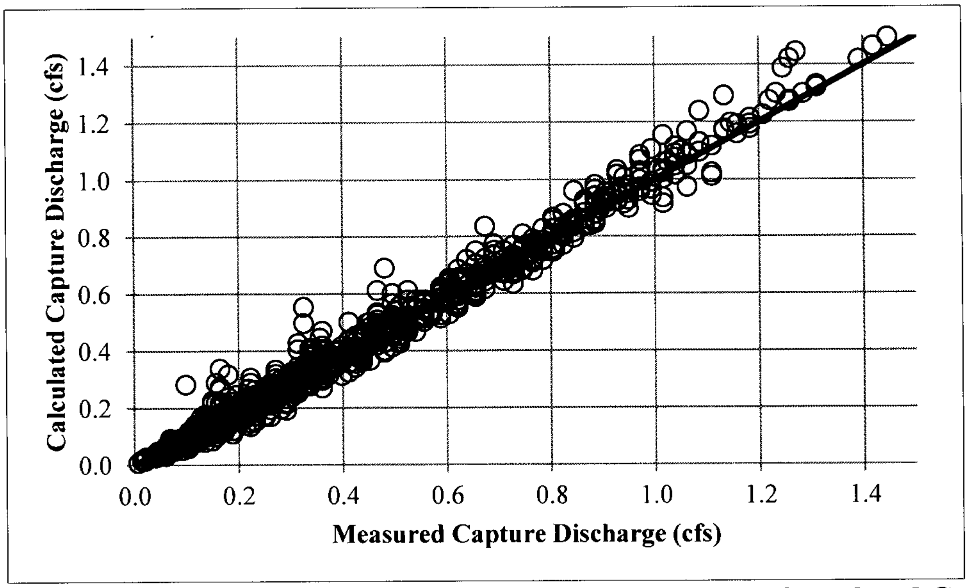

Figure 4-11 Comparison of Measured Capture Discharge and Calculated Capture Discharge (Equation 4.4) for Both Drain Sizes

4.5 Comparison between the New Equation and the FHWA Slotted Drain Equation

To compute the size and number of drains required to capture the total approach discharge, i.e., $Q_c = Q_a = Q$, where Q = the gutter flow rate, Equation 4.4 can be expressed as Equation 4.6:

$$N(L+W) = 0.5841 Q^{0.4375} S_0^{0.1770} \frac{1}{n^{0.5625} S_x^{0.3122}} \tag{4.6}$$

Equation 4.6 has a form similar to the FHWA slotted drain method (Brown et al. 2009); however, the power coefficient for the gutter flow rate, longitudinal slope, cross slope and Manning's roughness coefficient are different. The results of Equation 4.6 and the FHWA slotted drain method have been calculated and compared. The drain sizes calculated by the FHWA method are 1.29 to 2.76 times larger than drain sizes calculated using Equation 4.6. Because the FHWA slotted drain method has four parameters, it would be difficult to apply a correction factor to the equation to make it consistent with Equation 4.6.

4.6 Non-Linear Regression Method

To determine the effect of the drain width (W) and the number of open drains (N), non-linear regression analysis was carried out using the IBM SPSS statistics data editor. For this analysis an additional power term (γ) is added to the number of open drains (N) and a coefficient (b) is added in front of the drain width. Equation 4.4 is rewritten as

$$Q_c = aS^{\alpha} S_x^{\beta} (L + bW) N^{\gamma} \sqrt{g} \left(\frac{2y}{3}\right)^{1.5} \tag{4.7}$$

The model results are summarized in Table 4-2 with the R^2=0.99.

Table 4-2 Estimated Values from IBM SPSS Statistics Data Editor

Parameter		Std. Error	95% Confidence Interval Lower Bound	Upper Bound
a	.464	.014	.437	.491
α	.116	.002	.112	.120
β	-.272	.007	-.283	-.262
γ	.867	.009	.852	.882
b	1.082	.049	.985	1.178

Since b =1.082 is very close to 1, Equation 4.7 can be rewritten as

$$Q_c = aS_0^{\alpha} S_x^{\beta}(L+W)N^{\gamma}\sqrt{g}(\frac{2y}{3})^{1.5} \quad (4.8)$$

With $b = 1$, the estimated values for the other parameters are listed in Table 4-3 with R^2=0.99. The predicted capture discharge for $b = 1.082$ and $b = 1$ versus the measured capture discharge are plotted in Figure 4-12. The performances of both models are almost identical. Therefore, the assumption that the capture discharge is proportional to the drain width, i.e., $b = 1$, is verified as shown in Equation 4.8

Table 4-3 Estimated Values from IBM SPSS Statistics Data Editor for $b = 1$

Parameter	Estimate	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
a	.479	.011	.458	.500
α	.116	.002	.113	.120
β	-.273	.006	-.284	-.262
γ	.867	.008	.852	.882

As shown in Table 4-3, the estimated power (γ) on N is 0.867, which is less than unity. A gamma value less than unity suggest that the capture efficiency of individual drains decreases with number of drains open (N). Figure 4-13, which plots residuals for $\gamma = 0.867$ and $\gamma = 1$, shows clearly the residuals spread out evenly when $\gamma = 0.867$. When $\gamma = 1$, the residuals are mostly positive for $N = 1$ and 2 and mostly negative for $N = 5$. The predicted capture discharges for both models have been compared with the measured capture discharge, as shown in Figure 4-12. The root mean squared error has been calculated as 0.099 cfs for $\gamma = 0.867$ and 0.122 cfs for $\gamma = 1$, which is not significant for such a large scale physical model. Therefore, the simple model of Equation 4.4 is recommended.

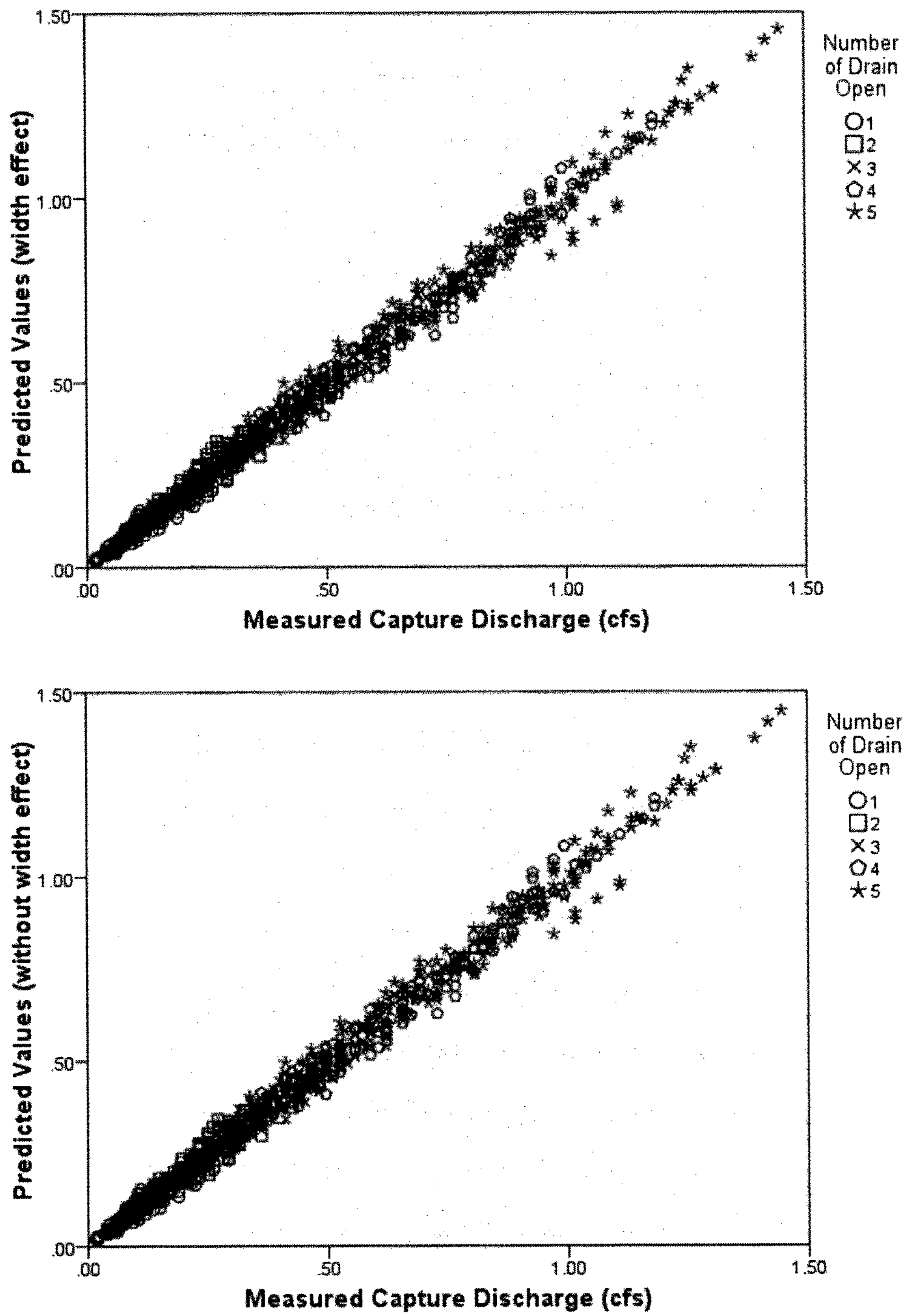

Figure 4-12 Predicted Discharge with Width Coefficients of b =1.082 and b = 1 vs. Measured Capture Discharge

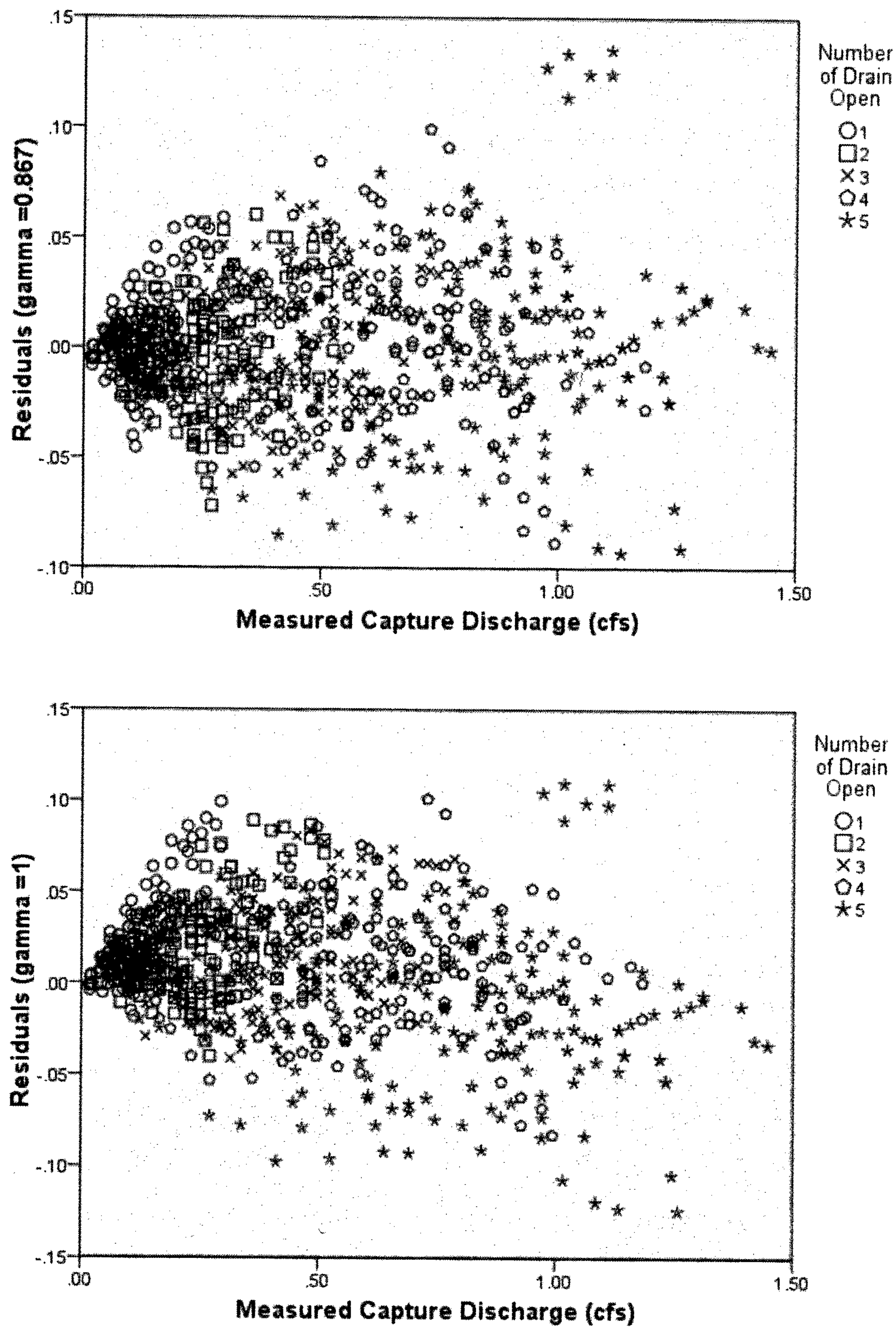

Figure 4-13 Effect of the Number of the Open Drains (N) on the Hydraulic Performance

Chapter 5. Design Guidance

Design guidance was implemented to determine the capture discharge of rectangular deck drains required for a given set of parameters of a bridge. A flow chart is also presented in Figure 5-1 to outline the procedure. The guidance provides an example, and both English and SI Units are calculated.

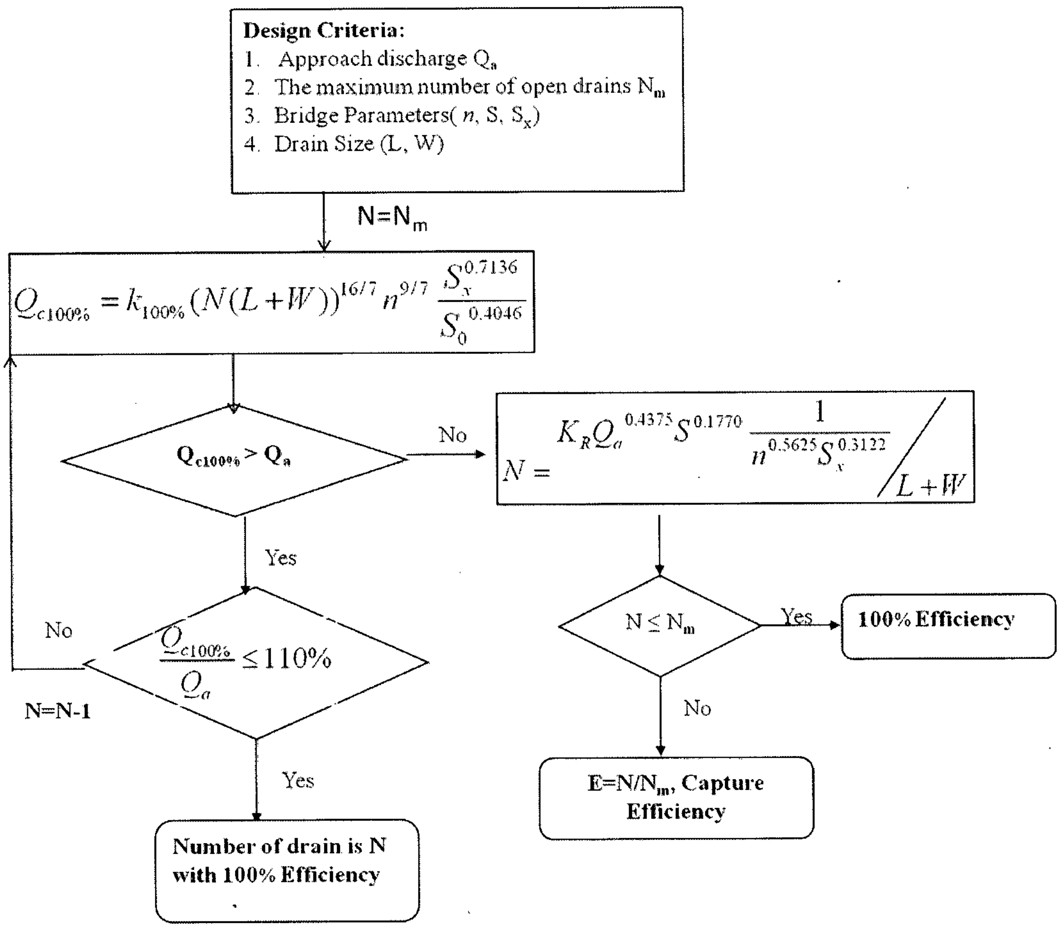

Figure 5-1 Design Flow Chart for Rectangular Drain

5.1 Design Steps

The detailed design steps are listed as follows:

Step 1: Determine 100% efficiency capture discharge.

The typical rectangular deck drains have two different sizes: 4in. × 8in. and 6in. × 8in. When the maximum number of drains, the drain size, and bridge characteristics are known, the 100% efficiency capture discharge for the maximum number of drains is determined by Equation 5.1.

$$Q_{c100\%} = k_{100\%}(N_m(L+W))^{16/7} n^{9/7} \frac{S_x^{0.7136}}{S_0^{0.4046}} \tag{5.1}$$

where N_m= number of drains required to intercept total gutter flow

L = nominate length of the drain, ft (m)
W= nominate width of the drain, ft (m)
$k_{100\%}$= 3.4176 for English units (1.4598 for SI)
S_0= longitudinal slope, ft/ft (m/m)
S_x= cross slope, ft/ft (m/m)
n = Manning's roughness coefficient

Step 2: Determine the number of drains required.
When the approach flow is lower than the 100% capture discharge, the ratio of the 100% capture discharge to the approach discharge needs to determine. When the ratio is less than 110%, the number of drain for calculating 100% capture discharge is the 100% efficiency drain number. Otherwise, the 100% capture discharge needs to be determined for N=N-1. Following the loop until either the ratio is less than 110% or the approach flow is higher than the 100% capture discharge, the number of the rectangular deck drain openings can then be determined by Equation 5.2:

$$N = \frac{K_R Q_a^{0.4375} S^{0.1770} \dfrac{1}{n^{0.5625} S_x^{0.3122}}}{L+W} \qquad (5.2)$$

where N = number of drains required to intercept total gutter flow
L = length of the drain, ft (m)
W = width of the drain, ft (m)
K_R = 0.5841 for English units (0.8476 for SI)
Q = total gutter flow, cfs (m^3/s)
S = longitudinal slope, ft/ft (m/m)
S_x = cross slope, ft/ft (m/m)
n = Manning's roughness coefficient

Step 3: Determine the efficiency of drain if the drain number excess the maximum drain number.
When N is greater than the maximum drain number (N_m), efficiency of the rectangular deck drains is determined by Equation 5.3:

$$E = \frac{N_m}{N} \qquad (5.3)$$

where E= efficiency

5.1.1 Example 1

Given: A bridge with the following design criteria and characteristics:
S = 0.01 ft/ft (m/m)
S_x = 0.02 ft/ft (m/m)
Q_a = 0.39 cfs (0.011 m^3/s)
n = 0.016
Nm = 7
Drain size: 4in. × 8in. (0.101 × 0.203 m)

Find: The number of open drains required to intercept total approach discharge and the efficiency if the number exceeds the maximum number of drains (N_m).

5.1.1.1 Solution for English Units

__Step 1: Determine 100% efficiency capture discharge.__

$$Q_{c100\%} = k_{100\%}(N_m(L+W))^{16/7} n^{9/7} \frac{S_x^{0.7136}}{S_0^{0.4046}}$$

$$Q_{c100\%} = 3.4176\,(7(8/12 + 4/12))^{16/7} n^{9/7} \frac{S_x^{0.7136}}{S_0^{0.4046}} = 0.5665\ cfs$$

$$Q_{c100\%} = 0.5665 > 0.39 cfs$$

__Step 2: Determine the number of drains required.__

$$\frac{Q_{c100\%}}{Q_a} = \frac{0.5665}{0.39} = 145\% > 110\%$$

$$N = 7 - 1 = 6$$

$$Q_{c100\%} = k_{100\%}(N_m(L+W))^{16/7} n^{9/7} \frac{S_x^{0.7136}}{S_0^{0.4046}}$$

$$= 3.4176(6(8/12 + 4/12))^{16/7} n^{9/7} \frac{S_x^{0.7136}}{S_0^{0.4046}}$$

$$= 0.398 cfs$$

$$\frac{Q_{c100\%}}{Q_a} = \frac{0.398}{0.39} \approx 102\%$$

$$N = 6$$

5.1.1.2 Solution for SI Units

__Step 1: Determine 100% efficiency capture discharge.__

$$Q_{c100\%} = k_{100\%}(N_m(L+W))^{16/7} n^{9/7} \frac{S_x^{0.7136}}{S_0^{0.4046}}$$

$$Q_{c100\%} = 1.4598(7(0.101 + 0.203))^{16/7} n^{9/7} \frac{S_x^{0.7136}}{S_0^{0.4046}} = 0.0159 m^3$$

$$Q_{c100\%} = 0.0159 > 0.011 m^3$$

__Step 2: Determine the number of drains required.__

$$\frac{Q_{c100\%}}{Q_a} = \frac{0.0159}{0.011} = 145\%$$

$$N = 7 - 1 = 6$$

$$Q_{c100\%} = k_{100\%}(N_m(L+W))^{16/7} n^{9/7} \frac{S_x^{0.7136}}{S_0^{0.4046}}$$

$$Q_{c100\%} = 1.4598(6(0.101+0.203))^{16/7} n^{9/7} \frac{S_x^{0.7136}}{S_0^{0.4046}} = 0.0112 m^3$$

$$\frac{Q_{c100\%}}{Q_a} = \frac{0.0112}{0.11} = 102\%$$

$$N = 6$$

5.1.2 Example 2

Given: A bridge with the following design criteria and characteristics:

S = 0.01 ft/ft (m/m)
S_x = 0.02 ft/ft (m/m)
Q_a = 1.77 cfs (0.05 m^3/s)
n = 0.016
Nm = 7
Drain size: 4in. × 8in. (0.101 × 0.203 m)

Find: The number of open drains required to intercept total approach discharge and the efficiency if the number exceeds the maximum number of drains (N_m).

5.1.2.1 Solution for English Units

Step 1: Determine100% efficiency capture discharge

$$Q_{c100\%} = k_{100\%}(N_m(L+W))^{16/7} n^{9/7} \frac{S_x^{0.7136}}{S_0^{0.4046}}$$

$$Q_{c100\%} = 3.4176(7(8/12 + 4/12))^{16/7} n^{9/7} \frac{S_x^{0.7136}}{S_0^{0.4046}} = 0.5665\ cfs$$

$$Q_{c100\%} = 0.5665 < 1.77 cfs$$

Step 2: Determine the number of drains required

$$N = \frac{K_R Q_a^{0.4375} S_0^{0.1770} \frac{1}{n^{0.5625} S_x^{0.3122}}}{L+W}$$

$$N = \frac{(0.5841 Q^{0.4375} S_0^{0.1770} \frac{1}{n^{0.5625} S_x^{0.3122}})}{L+W}$$

$$N = \frac{(0.5841(1.77)^{0.4375}(.01)^{0.1770}\frac{1}{(0.016)^{0.5625}(0.02)^{0.3122}})}{(4/12+8/12)}$$

$N = 11.57 > 7$

Step 3: Determine the efficiency for 7 drains

$$E = \frac{N_m}{N} = \frac{7}{11.57} = 60.5\%$$

5.1.2.2 Solution for SI Units

Step 1: Determine 100% efficiency capture discharge

$$Q_{c100\%} = k_{100\%}(N_m(L+W))^{16/7} n^{9/7} \frac{S_x^{0.7136}}{S_0^{0.4046}}$$

$$Q_{c100\%} = 1.4598(7(0.101+0.203))^{16/7} n^{9/7} \frac{S_x^{0.7136}}{S_0^{0.4046}} = 0.016m^3$$

$$Q_{c100\%} = 0.016 < 0.05m^3$$

Step 2: Determine the number of drains required

$$N = \left. K_R Q_a^{0.4375} S_0^{0.1770} \frac{1}{n^{0.5625} S_x^{0.3122}} \middle/ L+W \right.$$

$$N = \frac{(0.8476)(0.05)^{0.4375}(.01)^{0.1770}\frac{1}{(0.016)^{0.5625}(0.02)^{0.3122}}}{0.101+0.203}$$

$$N = \frac{3.527}{(0.203+0.101)} = 11.60 > 7$$

Step 3: Determine the efficiency for 7 drains

$$E = \frac{N_m}{N} = \frac{7}{11.60} = 60.3\%$$

Chapter 6. Summary and Conclusions

The study was concerned with the capacity of a new type of bridge deck drain. The ultimate objective was to obtain an accurate predictive equation for the hydraulic performance of rectangular bridge deck drains. The physical model has been reconstructed to represent one lane of the bridge and was built to change the longitudinal and cross slope easily. Two different drain sizes, 4 by 8 inches and 6 by 8 inches, were constructed of Plexiglas so that the behavior of the flow inside of the inlet can be observed. For each drain, many tests (586 for 4 by 8 in., 236 for 6 by 8 in.) were conducted for a variety of longitudinal slope (S_0), cross slopes (S_x), drain openings (N), and approach discharge (Q_a). Measurements in each test included the head on the V-notch weir from two reservoirs as well as ponding widths (spread) and curb depths at a number of stations along the deck.

The data measured from the physical models indicate that runoff capture is predicted by a weir-type equation. The investigation of the FHWA slotted drain method (Brown et al. 2009), shows the equation underestimates the capacity of the rectangular deck drains. A new equation has been successfully developed and has high agreement with the physical model data for both drain sizes. It is a function of the approach discharge, Manning's coefficient, cross slope, and longitudinal slope as expressed in Equation 4.4. It also indicates the capture discharge is proportional to the product of the number of the drains, drain length, and drain width. In summary, the hydraulic performance for rectangular bridge deck drains has been investigated and an accurate equation has been developed to guide the design of rectangular deck drains.

6.1 Conclusion

The study resulted in the following conclusions:

1. The physical study model showed the approach discharge reached normal flow before the drain openings. The dye tests illustrated the flow directions into the drain inlets and indicated that the flow into the drain behaves like flow over a weir. Therefore, water depth in front of the drain was a key parameter in determining the hydraulic performance. The hydraulic performance was the same for the 4in. × 8in. drains throughout the series since the water depths at the different openings were very similar. For the 6in. × 8in. drains, the hydraulic performance decreased slightly as more drains were added in the series because the larger width drains increased the capture discharge and decreased the water depth for the subsequent drain opening.
2. The data measured from the physical model indicated the capture discharge could be predicted by a weir-type equation. The hydraulic performance increased with drain size and number of drains. With the same size drain and number of open drains, the capture discharge increased with larger cross slopes but decreased with larger longitudinal slopes of the bridge deck drain for the same approach discharge.
3. The investigation of the slotted drain method (Brown et al. 2009) revealed the capture discharge calculated from that equation underestimated the capacity of the rectangular deck drains. The comparison indicated that applying a correction factor for the adopted slotted drain method is difficult. Therefore, the slotted drain method is a conservative but not accurate method and a new equation was developed for the rectangular deck drain.

4. A new equation was successfully developed and has high agreement with the physical model data for both drain sizes. The capture discharge is the function of the approach discharge, Manning's roughness coefficient, cross slope, and longitudinal slope as expressed in Equation 4.4. This equation also indicated the capture discharge is proportional to the product of the number of the open drains, drain length, and drain width.
5. Extensive data analysis using the IBM SPSS statistics data editor demonstrated that the capture discharge is proportional to the drain length and drain width. It also revealed decreasing capture discharge along the flow direction, i.e., the power of the number of drains (N) is less than 1.

6.2 Future Work

As noted in Section 4.2, the Manning's roughness coefficient appears to decrease for small slopes. This decrease could greatly impact design spacing of inlet structures on bridges and roadways with small grades. In this study, using the same Manning's coefficient (n= 0.016) would correspond to more than 10% increase in both spread and curb depth. Application of Manning's equation for pavement drainage assumes that the slope of the energy-grade-line is the same as the slope of the pavement surface. However, under conditions where the slope is sufficiently small, the assumption that gravity is the only driving force for flow is not valid, and analysis based on Manning's equation with a constant Manning's coefficient may not be appropriate. Further research can address questions associated with pavement drainage under small slope conditions, application of Manning's equation, possible modification to Manning's *n* to be applied where appropriate, and a fundamental understanding of flow behavior under small slope conditions.

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Appendix A. Experimental Data

Test No. = Test Number
W = Drain Width (in.)
N = Number of Open Drains
S_x = Cross Slope (ft/ft)
S = Longitudinal Slope (ft/ft)
y = calculated curb depth (ft)
Q_c = Capture Discharge (cfs)
Q_a = Approach Discharge (cfs)
n = Manning's Roughness Coefficient

Table A-1 Experimental Data

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
1	4	1	0.0214	0.001	0.107	0.0595	0.1694	0.012
2	4	1	0.0214	0.001	0.132	0.1040	0.3548	0.012
3	4	1	0.0214	0.001	0.149	0.1222	0.5076	0.012
4	4	1	0.0214	0.001	0.167	0.1565	0.6969	0.012
5	4	1	0.0214	0.001	0.187	0.1640	0.9105	0.012
6	4	1	0.0214	0.001	0.202	0.1961	1.1239	0.012
7	4	2	0.0214	0.001	0.120	0.1222	0.1996	0.012
8	4	2	0.0214	0.001	0.134	0.1878	0.3595	0.012
9	4	2	0.0214	0.001	0.152	0.2317	0.5026	0.012
10	4	2	0.0214	0.001	0.169	0.2813	0.7194	0.012
11	4	2	0.0214	0.001	0.189	0.3138	0.9522	0.012
12	4	2	0.0214	0.001	0.179	0.3367	1.1410	0.012
13	4	3	0.0214	0.001	0.100	0.1422	0.1616	0.012
14	4	3	0.0214	0.001	0.132	0.2607	0.3382	0.012
15	4	3	0.0214	0.001	0.147	0.3367	0.5163	0.012
16	4	3	0.0214	0.001	0.165	0.4113	0.7032	0.012
17	4	3	0.0214	0.001	0.199	0.5250	1.1297	0.012
18	4	3	0.0214	0.001	0.209	0.5561	1.2838	0.012
19	4	3	0.0214	0.001	0.217	0.5882	1.3925	0.012
20	4	4	0.0214	0.001	0.104	0.1717	0.1773	0.012
21	4	4	0.0214	0.001	0.132	0.3138	0.3515	0.012
22	4	4	0.0214	0.001	0.152	0.4950	0.5466	0.012
23	4	4	0.0214	0.001	0.170	0.5250	0.6967	0.012
24	4	4	0.0214	0.001	0.188	0.6214	0.9352	0.012
25	4	4	0.0214	0.001	0.199	0.7277	1.1659	0.012
26	4	4	0.0214	0.001	0.212	0.7654	1.3215	0.012
27	4	4	0.0214	0.001	0.217	0.7654	1.4212	0.012
28	4	4	0.0214	0.001	0.223	0.8043	1.5697	0.012

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
29	4	5	0.0214	0.001	0.104	0.1640	0.1654	0.012
30	4	5	0.0214	0.001	0.132	0.3606	0.3743	0.012
31	4	5	0.0214	0.001	0.157	0.4950	0.5466	0.012
32	4	5	0.0214	0.001	0.177	0.5882	0.7104	0.012
33	4	5	0.0214	0.001	0.189	0.7277	0.9412	0.012
34	4	5	0.0214	0.001	0.220	1.0162	1.5112	0.012
35	4	5	0.0214	0.001	0.223	1.0162	1.5722	0.012
36	4	5	0.0214	0.001	0.228	1.0621	1.6835	0.012
37	4	5	0.0214	0.001	0.229	1.1093	1.8005	0.012
38	4	5	0.0214	0.001	0.233	1.1093	1.8371	0.012
39	4	1	0.0226	0.005	0.100	0.0555	0.2195	0.016
40	4	1	0.0226	0.005	0.119	0.0775	0.3483	0.016
41	4	1	0.0226	0.005	0.135	0.0983	0.5229	0.016
42	4	1	0.0226	0.005	0.155	0.1159	0.7206	0.016
43	4	1	0.0226	0.005	0.169	0.1353	0.9200	0.016
44	4	1	0.0226	0.005	0.173	0.1565	1.1502	0.016
45	4	2	0.0226	0.005	0.100	0.1159	0.2258	0.016
46	4	2	0.0226	0.005	0.119	0.1493	0.3539	0.016
47	4	2	0.0226	0.005	0.135	0.1878	0.5129	0.016
48	4	2	0.0226	0.005	0.154	0.2225	0.7323	0.016
49	4	2	0.0226	0.005	0.169	0.2508	0.9420	0.016
50	4	2	0.0226	0.005	0.182	0.2709	1.1152	0.016
51	4	2	0.0226	0.005	0.199	0.3251	1.4107	0.016
52	4	3	0.0226	0.005	0.100	0.1640	0.2156	0.016
53	4	3	0.0226	0.005	0.119	0.2225	0.3446	0.016
54	4	3	0.0226	0.005	0.138	0.2813	0.5129	0.016
55	4	3	0.0226	0.005	0.154	0.3367	0.7096	0.016
56	4	3	0.0226	0.005	0.172	0.3854	0.9258	0.016
57	4	3	0.0226	0.005	0.184	0.4520	1.1797	0.016
58	4	3	0.0226	0.005	0.205	0.4950	1.5112	0.016
59	4	4	0.0226	0.005	0.100	0.2047	0.2201	0.016
60	4	4	0.0226	0.005	0.120	0.3138	0.3913	0.016
61	4	4	0.0226	0.005	0.134	0.4113	0.5753	0.016
62	4	4	0.0226	0.005	0.154	0.4950	0.7659	0.016
63	4	4	0.0226	0.005	0.169	0.5561	0.9942	0.016
64	4	4	0.0226	0.005	0.189	0.6557	1.3835	0.016
65	4	4	0.0226	0.005	0.208	0.7654	1.7368	0.016
66	4	5	0.0226	0.005	0.100	0.2225	0.2330	0.016
67	4	5	0.0226	0.005	0.139	0.4382	0.5257	0.016
68	4	5	0.0226	0.005	0.172	0.6557	0.9476	0.016

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
69	4	5	0.0226	0.005	0.190	0.7847	1.3097	0.016
70	4	5	0.0226	0.005	0.205	0.8647	1.5559	0.016
71	4	5	0.0226	0.005	0.217	0.9065	1.9686	0.016
72	4	1	0.0238	0.01	0.088	0.0443	0.2084	0.016
73	4	1	0.0238	0.01	0.105	0.0681	0.3600	0.016
74	4	1	0.0238	0.01	0.119	0.0775	0.5156	0.016
75	4	1	0.0238	0.01	0.140	0.0983	0.7716	0.016
76	4	1	0.0238	0.01	0.158	0.1040	0.9895	0.016
77	4	1	0.0238	0.01	0.156	0.1099	1.1260	0.016
78	4	2	0.0238	0.01	0.088	0.0824	0.1864	0.016
79	4	2	0.0238	0.01	0.107	0.1222	0.3356	0.016
80	4	2	0.0238	0.01	0.129	0.1640	0.5246	0.016
81	4	2	0.0238	0.01	0.142	0.1961	0.7522	0.016
82	4	2	0.0238	0.01	0.160	0.2317	0.9971	0.016
83	4	2	0.0238	0.01	0.170	0.2508	1.2222	0.016
84	4	2	0.0238	0.01	0.179	0.2607	1.4185	0.016
85	4	2	0.0238	0.01	0.184	0.2709	1.5815	0.016
86	4	3	0.0238	0.01	0.092	0.1353	0.2034	0.016
87	4	3	0.0238	0.01	0.109	0.1961	0.3601	0.016
88	4	3	0.0238	0.01	0.123	0.2508	0.5217	0.016
89	4	3	0.0238	0.01	0.143	0.3027	0.7273	0.016
90	4	3	0.0238	0.01	0.155	0.3485	0.9367	0.016
91	4	3	0.0238	0.01	0.170	0.3729	1.1383	0.016
92	4	3	0.0238	0.01	0.175	0.3982	1.3477	0.016
93	4	3	0.0238	0.01	0.179	0.4113	1.4734	0.016
94	4	4	0.0238	0.01	0.092	0.1878	0.2356	0.016
95	4	4	0.0238	0.01	0.110	0.2508	0.3548	0.016
96	4	4	0.0238	0.01	0.128	0.3138	0.4934	0.016
97	4	4	0.0238	0.01	0.137	0.4382	0.7520	0.016
98	4	4	0.0238	0.01	0.157	0.4950	0.9611	0.016
99	4	4	0.0238	0.01	0.162	0.5250	1.1132	0.016
100	4	4	0.0238	0.01	0.172	0.5561	1.2838	0.016
101	4	4	0.0238	0.01	0.182	0.5882	1.3925	0.016
102	4	4	0.0238	0.01	0.187	0.6557	1.5836	0.016
103	4	4	0.0238	0.01	0.194	0.5882	1.6503	0.016
104	4	5	0.0238	0.01	0.094	0.1961	0.2135	0.016
105	4	5	0.0238	0.01	0.109	0.3138	0.3581	0.016
106	4	5	0.0238	0.01	0.128	0.3854	0.5076	0.016
107	4	5	0.0238	0.01	0.144	0.4950	0.7267	0.016
108	4	5	0.0238	0.01	0.159	0.6047	1.0029	0.016

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
109	4	5	0.0238	0.01	0.179	0.7093	1.3478	0.016
110	4	5	0.0238	0.01	0.189	0.7654	1.5896	0.016
111	4	5	0.0238	0.01	0.200	0.8241	1.8631	0.016
112	4	1	0.0252	0.02	0.077	0.0516	0.1802	0.016
113	4	1	0.0252	0.02	0.100	0.0681	0.3600	0.016
114	4	1	0.0252	0.02	0.117	0.0775	0.5435	0.016
115	4	1	0.0252	0.02	0.132	0.0875	0.7259	0.016
116	4	1	0.0252	0.02	0.135	0.1040	0.9895	0.016
117	4	2	0.0252	0.02	0.090	0.0928	0.2150	0.016
118	4	2	0.0252	0.02	0.103	0.1353	0.3670	0.016
119	4	2	0.0252	0.02	0.115	0.1565	0.5294	0.016
120	4	2	0.0252	0.02	0.139	0.1796	0.7200	0.016
121	4	2	0.0252	0.02	0.143	0.1961	0.9615	0.016
122	4	3	0.0252	0.02	0.078	0.1099	0.1476	0.016
123	4	3	0.0252	0.02	0.098	0.1796	0.3437	0.016
124	4	3	0.0252	0.02	0.110	0.2134	0.5053	0.016
125	4	3	0.0252	0.02	0.128	0.2508	0.7169	0.016
126	4	3	0.0252	0.02	0.142	0.2919	0.9476	0.016
127	4	3	0.0252	0.02	0.152	0.3138	1.1581	0.016
128	4	4	0.0252	0.02	0.089	0.1640	0.2156	0.016
129	4	4	0.0252	0.02	0.098	0.2317	0.3539	0.016
130	4	4	0.0252	0.02	0.117	0.2919	0.5143	0.016
131	4	4	0.0252	0.02	0.124	0.3729	0.7334	0.016
132	4	4	0.0252	0.02	0.139	0.4113	0.9363	0.016
133	4	4	0.0252	0.02	0.147	0.4661	1.1572	0.016
134	4	4	0.0252	0.02	0.157	0.4804	1.3046	0.016
135	4	5	0.0252	0.02	0.079	0.1878	0.2117	0.016
136	4	5	0.0252	0.02	0.099	0.2607	0.3289	0.016
137	4	5	0.0252	0.02	0.115	0.3367	0.5007	0.016
138	4	5	0.0252	0.02	0.129	0.4113	0.7032	0.016
139	4	5	0.0252	0.02	0.142	0.4950	0.9332	0.016
140	4	5	0.0252	0.02	0.149	0.5561	1.1442	0.016
141	4	5	0.0252	0.02	0.154	0.5882	1.2975	0.016
142	4	5	0.0252	0.02	0.160	0.6047	1.3894	0.016
143	4	1	0.0267	0.04	0.079	0.0555	0.1977	0.016
144	4	1	0.0267	0.04	0.090	0.0681	0.3494	0.016
145	4	1	0.0267	0.04	0.104	0.0824	0.5206	0.016
146	4	1	0.0267	0.04	0.114	0.0875	0.6922	0.016
147	4	1	0.0267	0.04	0.124	0.0983	0.8637	0.016
148	4	1	0.0267	0.04	0.121	0.0983	1.0261	0.016

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
149	4	2	0.0267	0.04	0.078	0.0983	0.2205	0.016
150	4	2	0.0267	0.04	0.090	0.1099	0.3233	0.016
151	4	2	0.0267	0.04	0.100	0.1493	0.5221	0.016
152	4	2	0.0267	0.04	0.112	0.1493	0.6443	0.016
153	4	2	0.0267	0.04	0.124	0.1493	0.7374	0.016
154	4	2	0.0267	0.04	0.133	0.1961	0.9615	0.016
155	4	2	0.0267	0.04	0.133	0.2134	1.0577	0.016
156	4	2	0.0267	0.04	0.138	0.2317	1.1172	0.016
157	4	3	0.0267	0.04	0.074	0.1222	0.1996	0.016
158	4	3	0.0267	0.04	0.095	0.1640	0.3357	0.016
159	4	3	0.0267	0.04	0.104	0.1961	0.4670	0.016
160	4	3	0.0267	0.04	0.117	0.2134	0.6247	0.016
161	4	3	0.0267	0.04	0.124	0.2411	0.7972	0.016
162	4	3	0.0267	0.04	0.130	0.2709	0.9802	0.016
163	4	3	0.0267	0.04	0.133	0.2919	1.1160	0.016
164	4	3	0.0267	0.04	0.140	0.3027	1.2092	0.016
165	4	4	0.0267	0.04	0.077	0.1565	0.2161	0.016
166	4	4	0.0267	0.04	0.092	0.2134	0.3421	0.016
167	4	4	0.0267	0.04	0.105	0.2709	0.4933	0.016
168	4	4	0.0267	0.04	0.115	0.3251	0.6736	0.016
169	4	4	0.0267	0.04	0.125	0.3485	0.8289	0.016
170	4	4	0.0267	0.04	0.133	0.3854	1.0766	0.016
171	4	4	0.0267	0.04	0.139	0.4246	1.2488	0.016
172	4	4	0.0267	0.04	0.140	0.4246	1.3524	0.016
173	4	5	0.0267	0.04	0.078	0.1640	0.1814	0.016
174	4	5	0.0267	0.04	0.089	0.2317	0.3091	0.016
175	4	5	0.0267	0.04	0.102	0.2919	0.4484	0.016
176	4	5	0.0267	0.04	0.109	0.3606	0.6213	0.016
177	4	5	0.0267	0.04	0.119	0.4113	0.7719	0.016
178	4	5	0.0267	0.04	0.124	0.4382	0.9042	0.016
179	4	5	0.0267	0.04	0.130	0.4520	1.0240	0.016
180	4	5	0.0267	0.04	0.137	0.4661	1.1218	0.016
181	4	5	0.0267	0.04	0.138	0.4661	1.1938	0.016
182	4	1	0.0413	0.001	0.070	0.0172	0.0185	0.012
183	4	1	0.0413	0.001	0.095	0.0407	0.0533	0.012
184	4	1	0.0413	0.001	0.117	0.0626	0.1054	0.012
185	4	1	0.0413	0.001	0.133	0.0775	0.1681	0.012
186	4	1	0.0413	0.001	0.170	0.1222	0.3576	0.012
187	4	1	0.0413	0.001	0.192	0.1493	0.5221	0.012
188	4	1	0.0413	0.001	0.219	0.1796	0.7357	0.012

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
189	4	1	0.0413	0.001	0.229	0.1961	0.9615	0.012
190	4	2	0.0413	0.001	0.119	0.1122	0.1157	0.012
191	4	2	0.0413	0.001	0.135	0.1380	0.1704	0.012
192	4	2	0.0413	0.001	0.168	0.2317	0.3476	0.012
193	4	2	0.0413	0.001	0.198	0.2709	0.5026	0.012
194	4	2	0.0413	0.001	0.217	0.3138	0.7251	0.012
195	4	2	0.0413	0.001	0.238	0.3606	0.9423	0.012
196	4	2	0.0413	0.001	0.254	0.4034	1.1499	0.012
197	4	2	0.0413	0.001	0.267	0.4246	1.3101	0.012
198	4	3	0.0413	0.001	0.170	0.3027	0.3345	0.012
199	4	3	0.0413	0.001	0.197	0.3854	0.4894	0.012
200	4	3	0.0413	0.001	0.217	0.4604	0.6739	0.012
201	4	3	0.0413	0.001	0.237	0.5250	0.9104	0.012
202	4	3	0.0413	0.001	0.254	0.5720	1.1186	0.012
203	4	3	0.0413	0.001	0.267	0.6047	1.2604	0.012
204	4	3	0.0413	0.001	0.272	0.6316	1.3856	0.012
205	4	3	0.0413	0.001	0.277	0.6557	1.4640	0.012
206	4	4	0.0413	0.001	0.169	0.3367	0.3412	0.012
207	4	4	0.0413	0.001	0.190	0.4661	0.4910	0.012
208	4	4	0.0413	0.001	0.217	0.6214	0.7277	0.012
209	4	4	0.0413	0.001	0.235	0.6840	0.9101	0.012
210	4	4	0.0413	0.001	0.253	0.7654	1.1212	0.012
211	4	4	0.0413	0.001	0.265	0.8241	1.2678	0.012
212	4	4	0.0413	0.001	0.274	0.8443	1.3909	0.012
213	4	4	0.0413	0.001	0.279	0.8939	1.4985	0.012
214	4	4	0.0413	0.001	0.288	0.9278	1.5836	0.012
215	4	4	0.0413	0.001	0.293	0.9278	1.6556	0.012
216	4	4	0.0413	0.001	0.297	0.9365	1.7329	0.012
217	4	5	0.0413	0.001	0.198	0.4950	0.4953	0.012
218	4	5	0.0413	0.001	0.218	0.6733	0.6863	0.012
219	4	5	0.0413	0.001	0.237	0.7847	0.8722	0.012
220	4	5	0.0413	0.001	0.254	0.8855	1.0989	0.012
221	4	5	0.0413	0.001	0.267	0.9408	1.2391	0.012
222	4	5	0.0413	0.001	0.283	1.0390	1.4826	0.012
223	4	5	0.0413	0.001	0.293	1.0621	1.6119	0.012
224	4	1	0.0425	0.005	0.057	0.0172	0.0278	0.016
225	4	1	0.0425	0.005	0.084	0.0386	0.0613	0.016
226	4	1	0.0425	0.005	0.095	0.0547	0.0998	0.016
227	4	1	0.0425	0.005	0.123	0.0727	0.1826	0.016
228	4	1	0.0425	0.005	0.154	0.0983	0.3590	0.016

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
229	4	1	0.0425	0.005	0.173	0.1313	0.5042	0.016
230	4	1	0.0425	0.005	0.195	0.1536	0.7002	0.016
231	4	1	0.0425	0.005	0.217	0.1878	0.9532	0.016
232	4	1	0.0425	0.005	0.225	0.2047	1.1541	0.016
233	4	2	0.0425	0.005	0.077	0.0599	0.0607	0.016
234	4	2	0.0425	0.005	0.097	0.0836	0.0924	0.016
235	4	2	0.0425	0.005	0.124	0.1286	0.1696	0.016
236	4	2	0.0425	0.005	0.153	0.1961	0.3454	0.016
237	4	2	0.0425	0.005	0.172	0.2508	0.5116	0.016
238	4	2	0.0425	0.005	0.197	0.2919	0.7300	0.016
239	4	2	0.0425	0.005	0.219	0.3367	0.9581	0.016
240	4	2	0.0425	0.005	0.230	0.3606	1.1649	0.016
241	4	3	0.0425	0.005	0.122	0.1394	0.1397	0.016
242	4	3	0.0425	0.005	0.153	0.2771	0.3083	0.016
243	4	3	0.0425	0.005	0.173	0.3485	0.4644	0.016
244	4	3	0.0425	0.005	0.197	0.4382	0.7258	0.016
245	4	3	0.0425	0.005	0.219	0.4891	0.9609	0.016
246	4	3	0.0425	0.005	0.229	0.5250	1.1738	0.016
247	4	3	0.0425	0.005	0.240	0.5342	1.3112	0.016
248	4	4	0.0425	0.005	0.152	0.3251	0.3276	0.016
249	4	4	0.0425	0.005	0.174	0.4661	0.5104	0.016
250	4	4	0.0425	0.005	0.199	0.5656	0.7236	0.016
251	4	4	0.0425	0.005	0.218	0.6316	0.9299	0.016
252	4	4	0.0425	0.005	0.230	0.6912	1.1432	0.016
253	4	4	0.0425	0.005	0.240	0.7277	1.2619	0.016
254	4	4	0.0425	0.005	0.249	0.7654	1.4212	0.016
255	4	5	0.0425	0.005	0.154	0.3557	0.3560	0.016
256	4	5	0.0425	0.005	0.173	0.5009	0.5037	0.016
257	4	5	0.0425	0.005	0.195	0.6557	0.7036	0.016
258	4	5	0.0425	0.005	0.219	0.7654	0.9147	0.016
259	4	5	0.0425	0.005	0.229	0.8362	1.1217	0.016
260	4	5	0.0425	0.005	0.228	0.8981	1.2911	0.016
261	4	5	0.0425	0.005	0.249	0.9150	1.3811	0.016
262	4	5	0.0425	0.005	0.257	0.9714	1.4964	0.016
263	4	5	0.0425	0.005	0.262	1.0071	1.5953	0.016
264	4	5	0.0425	0.005	0.264	1.0252	1.6706	0.016
265	4	5	0.0425	0.005	0.274	1.0856	1.8625	0.016
266	4	1	0.0432	0.01	0.052	0.0148	0.0206	0.016
267	4	1	0.0432	0.01	0.072	0.0328	0.0555	0.016
268	4	1	0.0432	0.01	0.088	0.0497	0.0948	0.016

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
269	4	1	0.0432	0.01	0.112	0.0637	0.1677	0.016
270	4	1	0.0432	0.01	0.139	0.0875	0.3482	0.016
271	4	1	0.0432	0.01	0.155	0.1040	0.5153	0.016
272	4	1	0.0432	0.01	0.175	0.1222	0.7104	0.016
273	4	1	0.0432	0.01	0.184	0.1353	0.9396	0.016
274	4	2	0.0432	0.01	0.074	0.0547	0.0565	0.016
275	4	2	0.0432	0.01	0.090	0.0869	0.1041	0.016
276	4	2	0.0432	0.01	0.112	0.1099	0.1694	0.016
277	4	2	0.0432	0.01	0.137	0.1878	0.3518	0.016
278	4	2	0.0432	0.01	0.154	0.2317	0.5026	0.016
279	4	2	0.0432	0.01	0.174	0.2508	0.7028	0.016
280	4	2	0.0432	0.01	0.193	0.2709	0.9266	0.016
281	4	2	0.0432	0.01	0.207	0.2919	1.1362	0.016
282	4	3	0.0432	0.01	0.090	0.1084	0.1084	0.016
283	4	3	0.0432	0.01	0.112	0.1640	0.1814	0.016
284	4	3	0.0432	0.01	0.139	0.2709	0.3584	0.016
285	4	3	0.0432	0.01	0.155	0.3367	0.5007	0.016
286	4	3	0.0432	0.01	0.173	0.3854	0.7221	0.016
287	4	3	0.0432	0.01	0.192	0.4246	0.9496	0.016
288	4	3	0.0432	0.01	0.207	0.4661	1.1572	0.016
289	4	3	0.0432	0.01	0.215	0.4950	1.2993	0.016
290	4	4	0.0432	0.01	0.119	0.2134	0.2140	0.016
291	4	4	0.0432	0.01	0.139	0.3251	0.3425	0.016
292	4	4	0.0432	0.01	0.155	0.4246	0.4927	0.016
293	4	4	0.0432	0.01	0.170	0.5099	0.6739	0.016
294	4	4	0.0432	0.01	0.190	0.5720	0.9087	0.016
295	4	4	0.0432	0.01	0.205	0.6047	1.0707	0.016
296	4	4	0.0432	0.01	0.215	0.6557	1.2772	0.016
297	4	4	0.0432	0.01	0.223	0.6733	1.3826	0.016
298	4	4	0.0432	0.01	0.227	0.6912	1.4955	0.016
299	4	5	0.0432	0.01	0.139	0.3606	0.3612	0.016
300	4	5	0.0432	0.01	0.159	0.4950	0.5055	0.016
301	4	5	0.0432	0.01	0.175	0.6214	0.6941	0.016
302	4	5	0.0432	0.01	0.197	0.7277	0.9238	0.016
303	4	5	0.0432	0.01	0.209	0.8043	1.1294	0.016
304	4	5	0.0432	0.01	0.218	0.8443	1.2825	0.016
305	4	5	0.0432	0.01	0.227	0.8855	1.4105	0.016
306	4	5	0.0432	0.01	0.230	0.9065	1.5279	0.016
307	4	5	0.0432	0.01	0.235	0.9278	1.6190	0.016
308	4	5	0.0432	0.01	0.240	0.9495	1.6959	0.016

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
309	4	5	0.0432	0.01	0.242	0.9714	1.7561	0.016
310	4	1	0.0437	0.02	0.098	0.0775	0.2311	0.016
311	4	1	0.0437	0.02	0.115	0.0875	0.3523	0.016
312	4	1	0.0437	0.02	0.136	0.0983	0.5503	0.016
313	4	1	0.0437	0.02	0.153	0.1197	0.7581	0.016
314	4	1	0.0437	0.02	0.171	0.1353	1.0208	0.016
315	4	2	0.0437	0.02	0.097	0.1286	0.2269	0.016
316	4	2	0.0437	0.02	0.114	0.1640	0.3437	0.016
317	4	2	0.0437	0.02	0.132	0.1878	0.5083	0.016
318	4	2	0.0437	0.02	0.152	0.2225	0.7475	0.016
319	4	2	0.0437	0.02	0.167	0.2317	0.9594	0.016
320	4	2	0.0437	0.02	0.179	0.2508	1.1573	0.016
321	4	3	0.0437	0.02	0.097	0.1878	0.2255	0.016
322	4	3	0.0437	0.02	0.116	0.2607	0.3590	0.016
323	4	3	0.0437	0.02	0.134	0.3027	0.5344	0.016
324	4	3	0.0437	0.02	0.154	0.3367	0.7749	0.016
325	4	3	0.0437	0.02	0.168	0.3729	0.9775	0.016
326	4	3	0.0437	0.02	0.181	0.4113	1.1767	0.016
327	4	4	0.0437	0.02	0.090	0.1796	0.1830	0.016
328	4	4	0.0437	0.02	0.116	0.3138	0.3581	0.016
329	4	4	0.0437	0.02	0.133	0.3854	0.5207	0.016
330	4	4	0.0437	0.02	0.151	0.4661	0.7268	0.016
331	4	4	0.0437	0.02	0.167	0.5099	0.9480	0.016
332	4	4	0.0437	0.02	0.187	0.5561	1.2838	0.016
333	4	4	0.0437	0.02	0.194	0.6047	1.4288	0.016
334	4	5	0.0437	0.02	0.096	0.2188	0.2188	0.016
335	4	5	0.0437	0.02	0.114	0.3367	0.3432	0.016
336	4	5	0.0437	0.02	0.131	0.4576	0.4999	0.016
337	4	5	0.0437	0.02	0.149	0.5561	0.7053	0.016
338	4	5	0.0437	0.02	0.165	0.6214	0.9285	0.016
339	4	5	0.0437	0.02	0.178	0.6804	1.1241	0.016
340	4	5	0.0437	0.02	0.187	0.7277	1.2838	0.016
341	4	5	0.0437	0.02	0.193	0.7465	1.4022	0.016
342	4	5	0.0437	0.02	0.198	0.7654	1.5044	0.016
343	4	5	0.0437	0.02	0.204	0.8043	1.6284	0.016
344	4	1	0.0461	0.04	0.098	0.0775	0.2415	0.016
345	4	1	0.0461	0.04	0.118	0.0875	0.3794	0.016
346	4	1	0.0461	0.04	0.133	0.0983	0.5503	0.016
347	4	1	0.0461	0.04	0.147	0.1040	0.7773	0.016
348	4	1	0.0461	0.04	0.153	0.1099	1.0164	0.016

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
349	4	2	0.0461	0.04	0.095	0.1222	0.2150	0.016
350	4	2	0.0461	0.04	0.114	0.1493	0.3539	0.016
351	4	2	0.0461	0.04	0.128	0.1717	0.5202	0.016
352	4	2	0.0461	0.04	0.143	0.1961	0.7211	0.016
353	4	2	0.0461	0.04	0.154	0.2134	0.9412	0.016
354	4	2	0.0461	0.04	0.165	0.2317	1.1172	0.016
355	4	3	0.0461	0.04	0.095	0.1565	0.2009	0.016
356	4	3	0.0461	0.04	0.109	0.2134	0.3174	0.016
357	4	3	0.0461	0.04	0.125	0.2411	0.4728	0.016
358	4	3	0.0461	0.04	0.142	0.2813	0.7332	0.016
359	4	3	0.0461	0.04	0.159	0.3138	0.9352	0.016
360	4	3	0.0461	0.04	0.167	0.3367	1.1410	0.016
361	4	4	0.0461	0.04	0.098	0.2047	0.2337	0.016
362	4	4	0.0461	0.04	0.113	0.2813	0.3494	0.016
363	4	4	0.0461	0.04	0.129	0.3606	0.5402	0.016
364	4	4	0.0461	0.04	0.145	0.4113	0.7480	0.016
365	4	4	0.0461	0.04	0.159	0.4661	0.9911	0.016
366	4	4	0.0461	0.04	0.173	0.4804	1.1716	0.016
367	4	4	0.0461	0.04	0.182	0.4950	1.2993	0.016
368	4	5	0.0461	0.04	0.099	0.2508	0.2546	0.016
369	4	5	0.0461	0.04	0.117	0.3606	0.3870	0.016
370	4	5	0.0461	0.04	0.127	0.4382	0.5257	0.016
371	4	5	0.0461	0.04	0.139	0.4950	0.7267	0.016
372	4	5	0.0461	0.04	0.159	0.5404	0.9386	0.016
373	4	5	0.0461	0.04	0.173	0.5882	1.1132	0.016
374	4	5	0.0461	0.04	0.177	0.6047	1.2958	0.016
375	4	5	0.0461	0.04	0.182	0.6214	1.4061	0.016
376	4	1	0.0606	0.001	0.077	0.0227	0.0228	0.016
377	4	1	0.0606	0.001	0.107	0.0474	0.0519	0.012
378	4	1	0.0606	0.001	0.128	0.0741	0.1107	0.012
379	4	1	0.0606	0.001	0.169	0.1099	0.2197	0.012
380	4	1	0.0606	0.001	0.198	0.1422	0.3556	0.012
381	4	1	0.0606	0.001	0.220	0.1796	0.5163	0.012
382	4	1	0.0606	0.001	0.249	0.2317	0.7567	0.012
383	4	1	0.0606	0.001	0.285	0.2508	1.0750	0.012
384	4	1	0.0606	0.001	0.286	0.2607	1.1462	0.012
385	4	2	0.0606	0.001	0.130	0.1161	0.1197	0.012
386	4	2	0.0606	0.001	0.155	0.1610	0.1874	0.012
387	4	2	0.0606	0.001	0.194	0.2508	0.3491	0.012
388	4	2	0.0606	0.001	0.220	0.3027	0.5126	0.012

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
389	4	2	0.0606	0.001	0.249	0.3606	0.7334	0.012
390	4	2	0.0606	0.001	0.273	0.4382	0.9632	0.012
391	4	2	0.0606	0.001	0.297	0.4661	1.1572	0.012
392	4	2	0.0606	0.001	0.307	0.4950	1.3393	0.012
393	4	3	0.0606	0.001	0.198	0.3606	0.3800	0.012
394	4	3	0.0606	0.001	0.222	0.4520	0.5395	0.012
395	4	3	0.0606	0.001	0.249	0.5250	0.7384	0.012
396	4	3	0.0606	0.001	0.275	0.6214	0.9652	0.012
397	4	3	0.0606	0.001	0.297	0.6733	1.1983	0.012
398	4	3	0.0606	0.001	0.309	0.7093	1.3651	0.012
399	4	3	0.0606	0.001	0.318	0.7093	1.4748	0.012
400	4	4	0.0606	0.001	0.222	0.5099	0.5204	0.012
401	4	4	0.0606	0.001	0.249	0.6214	0.6941	0.012
402	4	4	0.0606	0.001	0.275	0.7465	0.9105	0.012
403	4	4	0.0606	0.001	0.292	0.8043	1.1181	0.012
404	4	4	0.0606	0.001	0.307	0.8647	1.2893	0.012
405	4	4	0.0606	0.001	0.314	0.8855	1.3805	0.012
406	4	4	0.0606	0.001	0.325	0.9278	1.5160	0.012
407	4	4	0.0606	0.001	0.329	0.9278	1.5577	0.012
408	4	4	0.0606	0.001	0.334	0.9714	1.6536	0.012
409	4	4	0.0606	0.001	0.343	0.9936	1.7591	0.012
410	4	5	0.0606	0.001	0.275	0.8443	0.9218	0.012
411	4	5	0.0606	0.001	0.297	0.9714	1.1431	0.012
412	4	5	0.0606	0.001	0.307	1.0162	1.2769	0.012
413	4	5	0.0606	0.001	0.317	1.0856	1.4461	0.012
414	4	5	0.0606	0.001	0.329	1.1334	1.5580	0.012
415	4	5	0.0606	0.001	0.342	1.2455	1.7705	0.012
416	4	5	0.0606	0.001	0.349	1.2584	1.8466	0.012
417	4	5	0.0606	0.001	0.352	1.2713	1.9012	0.012
418	4	1	0.0607	0.005	0.067	0.0185	0.0207	0.016
419	4	1	0.0607	0.005	0.097	0.0451	0.0557	0.016
420	4	1	0.0607	0.005	0.114	0.0682	0.1010	0.016
421	4	1	0.0607	0.005	0.138	0.0983	0.1858	0.016
422	4	1	0.0607	0.005	0.175	0.1353	0.3764	0.016
423	4	1	0.0607	0.005	0.199	0.1640	0.5246	0.016
424	4	1	0.0607	0.005	0.227	0.1878	0.7438	0.016
425	4	1	0.0607	0.005	0.238	0.2134	0.9789	0.016
426	4	2	0.0607	0.005	0.115	0.1107	0.1122	0.016
427	4	2	0.0607	0.005	0.150	0.1796	0.2312	0.016
428	4	2	0.0607	0.005	0.175	0.2411	0.3698	0.016

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
429	4	2	0.0607	0.005	0.198	0.3138	0.5455	0.016
430	4	2	0.0607	0.005	0.225	0.3485	0.7731	0.016
431	4	2	0.0607	0.005	0.245	0.3854	0.9736	0.016
432	4	2	0.0607	0.005	0.264	0.3982	1.1447	0.016
433	4	2	0.0607	0.005	0.272	0.4113	1.3051	0.016
434	4	3	0.0607	0.005	0.117	0.1276	0.1276	0.016
435	4	3	0.0607	0.005	0.137	0.1796	0.1810	0.016
436	4	3	0.0607	0.005	0.173	0.3138	0.3428	0.016
437	4	3	0.0607	0.005	0.198	0.3982	0.5045	0.016
438	4	3	0.0607	0.005	0.223	0.4576	0.6987	0.016
439	4	3	0.0607	0.005	0.243	0.5250	0.9496	0.016
440	4	3	0.0607	0.005	0.259	0.5720	1.1376	0.016
441	4	3	0.0607	0.005	0.273	0.6047	1.2958	0.016
442	4	3	0.0607	0.005	0.282	0.6384	1.4427	0.016
443	4	4	0.0607	0.005	0.147	0.2225	0.2231	0.016
444	4	4	0.0607	0.005	0.174	0.3485	0.3492	0.016
445	4	4	0.0607	0.005	0.194	0.4804	0.4978	0.016
446	4	4	0.0607	0.005	0.223	0.6047	0.6953	0.016
447	4	4	0.0607	0.005	0.248	0.6912	0.9229	0.016
448	4	4	0.0607	0.005	0.259	0.7654	1.1220	0.016
449	4	4	0.0607	0.005	0.272	0.8043	1.2507	0.016
450	4	4	0.0607	0.005	0.280	0.8443	1.4004	0.016
451	4	4	0.0607	0.005	0.293	0.8855	1.5412	0.016
452	4	4	0.0607	0.005	0.297	0.9065	1.6343	0.016
453	4	4	0.0607	0.005	0.303	0.9278	1.6933	0.016
454	4	5	0.0607	0.005	0.223	0.6912	0.7106	0.016
455	4	5	0.0607	0.005	0.244	0.8443	0.9318	0.016
456	4	5	0.0607	0.005	0.262	0.9495	1.1291	0.016
457	4	5	0.0607	0.005	0.272	1.0162	1.2870	0.016
458	4	5	0.0607	0.005	0.283	1.0390	1.3996	0.016
459	4	5	0.0607	0.005	0.292	1.0856	1.5237	0.016
460	4	5	0.0607	0.005	0.300	1.1334	1.6284	0.016
461	4	5	0.0607	0.005	0.304	1.1455	1.6937	0.016
462	4	5	0.0607	0.005	0.315	1.2201	1.8934	0.016
463	4	5	0.0607	0.005	0.318	1.2328	1.9605	0.016
464	4	1	0.0606	0.01	0.059	0.0185	0.0240	0.016
465	4	1	0.0606	0.01	0.088	0.0451	0.0577	0.016
466	4	1	0.0606	0.01	0.102	0.0599	0.1006	0.016
467	4	1	0.0606	0.01	0.124	0.0775	0.1758	0.016
468	4	1	0.0606	0.01	0.157	0.1099	0.3607	0.016

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
469	4	1	0.0606	0.01	0.173	0.1222	0.5076	0.016
470	4	1	0.0606	0.01	0.197	0.1422	0.7142	0.016
471	4	1	0.0606	0.01	0.215	0.1640	0.9683	0.016
472	4	2	0.0606	0.01	0.100	0.1009	0.1044	0.016
473	4	2	0.0606	0.01	0.119	0.1286	0.1633	0.016
474	4	2	0.0606	0.01	0.152	0.2134	0.3233	0.016
475	4	2	0.0606	0.01	0.173	0.2508	0.4825	0.016
476	4	2	0.0606	0.01	0.194	0.2709	0.7090	0.016
477	4	2	0.0606	0.01	0.213	0.2919	0.8965	0.016
478	4	2	0.0606	0.01	0.230	0.3251	1.1099	0.016
479	4	3	0.0606	0.01	0.102	0.1161	0.1164	0.016
480	4	3	0.0606	0.01	0.119	0.1422	0.1424	0.016
481	4	3	0.0606	0.01	0.153	0.2919	0.3265	0.016
482	4	3	0.0606	0.01	0.175	0.3606	0.4892	0.016
483	4	3	0.0606	0.01	0.194	0.4382	0.6989	0.016
484	4	3	0.0606	0.01	0.218	0.4950	0.9250	0.016
485	4	3	0.0606	0.01	0.230	0.4950	1.0832	0.016
486	4	3	0.0606	0.01	0.240	0.5561	1.3025	0.016
487	4	3	0.0606	0.01	0.248	0.5720	1.4163	0.016
488	4	4	0.0606	0.01	0.154	0.3367	0.3398	0.016
489	4	4	0.0606	0.01	0.178	0.4804	0.5043	0.016
490	4	4	0.0606	0.01	0.197	0.5882	0.6980	0.016
491	4	4	0.0606	0.01	0.218	0.6557	0.9165	0.016
492	4	4	0.0606	0.01	0.237	0.7093	1.1339	0.016
493	4	4	0.0606	0.01	0.243	0.7465	1.2868	0.016
494	4	4	0.0606	0.01	0.249	0.7847	1.4061	0.016
495	4	4	0.0606	0.01	0.260	0.8241	1.5519	0.016
496	4	4	0.0606	0.01	0.262	0.8443	1.6605	0.016
497	4	5	0.0606	0.01	0.200	0.6733	0.6987	0.016
498	4	5	0.0606	0.01	0.220	0.8082	0.9279	0.016
499	4	5	0.0606	0.01	0.234	0.8771	1.1241	0.016
500	4	5	0.0606	0.01	0.245	0.9408	1.3087	0.016
501	4	5	0.0606	0.01	0.255	0.9936	1.4456	0.016
502	4	5	0.0606	0.01	0.258	1.0162	1.5412	0.016
503	4	5	0.0606	0.01	0.265	1.0162	1.6043	0.016
504	4	5	0.0606	0.01	0.278	1.0505	1.8160	0.016
505	4	1	0.0619	0.02	0.057	0.0198	0.0217	0.016
506	4	1	0.0619	0.02	0.082	0.0407	0.0544	0.016
507	4	1	0.0619	0.02	0.092	0.0599	0.0926	0.016
508	4	1	0.0619	0.02	0.114	0.0775	0.1873	0.016

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
509	4	1	0.0619	0.02	0.140	0.1099	0.3706	0.016
510	4	1	0.0619	0.02	0.159	0.1222	0.5335	0.016
511	4	1	0.0619	0.02	0.175	0.1353	0.7235	0.016
512	4	1	0.0619	0.02	0.185	0.1493	0.9535	0.016
513	4	2	0.0619	0.02	0.092	0.0903	0.0961	0.016
514	4	2	0.0619	0.02	0.112	0.1493	0.1902	0.016
515	4	2	0.0619	0.02	0.140	0.1961	0.3526	0.016
516	4	2	0.0619	0.02	0.158	0.2280	0.5198	0.016
517	4	2	0.0619	0.02	0.180	0.2508	0.6890	0.016
518	4	2	0.0619	0.02	0.197	0.2813	0.9370	0.016
519	4	2	0.0619	0.02	0.212	0.2919	1.1362	0.016
520	4	3	0.0619	0.02	0.079	0.0682	0.0682	0.016
521	4	3	0.0619	0.02	0.093	0.1122	0.1127	0.016
522	4	3	0.0619	0.02	0.113	0.1640	0.1719	0.016
523	4	3	0.0619	0.02	0.142	0.2919	0.3514	0.016
524	4	3	0.0619	0.02	0.158	0.3251	0.4892	0.016
525	4	3	0.0619	0.02	0.175	0.3854	0.6992	0.016
526	4	3	0.0619	0.02	0.195	0.4382	0.9332	0.016
527	4	3	0.0619	0.02	0.212	0.4661	1.1572	0.016
528	4	3	0.0619	0.02	0.223	0.4804	1.2847	0.016
529	4	4	0.0619	0.02	0.108	0.1640	0.1641	0.016
530	4	4	0.0619	0.02	0.138	0.3251	0.3276	0.016
531	4	4	0.0619	0.02	0.159	0.4382	0.4861	0.016
532	4	4	0.0619	0.02	0.174	0.5099	0.6895	0.016
533	4	4	0.0619	0.02	0.194	0.5561	0.8812	0.016
534	4	4	0.0619	0.02	0.213	0.6214	1.1164	0.016
535	4	4	0.0619	0.02	0.218	0.6557	1.2942	0.016
536	4	4	0.0619	0.02	0.223	0.6557	1.3651	0.016
537	4	4	0.0619	0.02	0.234	0.6733	1.4580	0.016
538	4	5	0.0619	0.02	0.137	0.3367	0.3367	0.016
539	4	5	0.0619	0.02	0.157	0.4661	0.4691	0.016
540	4	5	0.0619	0.02	0.174	0.6214	0.6532	0.016
541	4	5	0.0619	0.02	0.195	0.7093	0.9228	0.016
542	4	5	0.0619	0.02	0.209	0.8043	1.1181	0.016
543	4	5	0.0619	0.02	0.217	0.8241	1.2623	0.016
544	4	5	0.0619	0.02	0.223	0.8443	1.4004	0.016
545	4	5	0.0619	0.02	0.237	0.8647	1.5118	0.016
546	4	5	0.0619	0.02	0.240	0.8855	1.6040	0.016
547	4	5	0.0619	0.02	0.243	0.8981	1.6635	0.016
548	4	1	0.0609	0.04	0.040	0.0072	0.0073	0.016

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
549	4	1	0.0609	0.04	0.048	0.0198	0.0256	0.016
550	4	1	0.0609	0.04	0.083	0.0599	0.0908	0.016
551	4	1	0.0609	0.04	0.109	0.0727	0.2220	0.016
552	4	1	0.0609	0.04	0.128	0.0875	0.3584	0.016
553	4	1	0.0609	0.04	0.143	0.0983	0.5229	0.016
554	4	1	0.0609	0.04	0.162	0.1159	0.7544	0.016
555	4	1	0.0609	0.04	0.169	0.1286	0.9934	0.016
556	4	2	0.0609	0.04	0.058	0.0407	0.0407	0.016
557	4	2	0.0609	0.04	0.069	0.0682	0.0683	0.016
558	4	2	0.0609	0.04	0.094	0.1161	0.1333	0.016
559	4	2	0.0609	0.04	0.114	0.1493	0.2368	0.016
560	4	2	0.0609	0.04	0.124	0.1565	0.3362	0.016
561	4	2	0.0609	0.04	0.142	0.1796	0.4934	0.016
562	4	2	0.0609	0.04	0.160	0.2134	0.7384	0.016
563	4	2	0.0609	0.04	0.179	0.2317	0.9971	0.016
564	4	3	0.0609	0.04	0.069	0.0711	0.0712	0.016
565	4	3	0.0609	0.04	0.094	0.1506	0.1519	0.016
566	4	3	0.0609	0.04	0.114	0.2134	0.2424	0.016
567	4	3	0.0609	0.04	0.129	0.2508	0.3730	0.016
568	4	3	0.0609	0.04	0.144	0.2919	0.5235	0.016
569	4	3	0.0609	0.04	0.164	0.3367	0.7480	0.016
570	4	3	0.0609	0.04	0.180	0.3485	0.9532	0.016
571	4	3	0.0609	0.04	0.192	0.3854	1.1509	0.016
572	4	4	0.0609	0.04	0.108	0.2047	0.2047	0.016
573	4	4	0.0609	0.04	0.128	0.3027	0.3243	0.016
574	4	4	0.0609	0.04	0.142	0.3729	0.4951	0.016
575	4	4	0.0609	0.04	0.163	0.4382	0.7300	0.016
576	4	4	0.0609	0.04	0.173	0.4661	0.9181	0.016
577	4	4	0.0609	0.04	0.187	0.4950	1.0997	0.016
578	4	4	0.0609	0.04	0.199	0.5404	1.3251	0.016
579	4	5	0.0609	0.04	0.129	0.3606	0.3630	0.016
580	4	5	0.0609	0.04	0.144	0.4804	0.5247	0.016
581	4	5	0.0609	0.04	0.162	0.5404	0.7044	0.016
582	4	5	0.0609	0.04	0.179	0.5882	0.9020	0.016
583	4	5	0.0609	0.04	0.190	0.6214	1.0875	0.016
584	4	5	0.0609	0.04	0.195	0.6557	1.2604	0.016
585	4	5	0.0609	0.04	0.207	0.6912	1.4189	0.016
586	4	5	0.0609	0.04	0.210	0.6912	1.4955	0.016
587	6	1	0.0218	0.005	0.0853	0.0595	0.1694	0.016
588	6	1	0.0218	0.005	0.1128	0.0983	0.3394	0.016

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
589	6	1	0.0218	0.005	0.1303	0.1222	0.5076	0.016
590	6	1	0.0218	0.005	0.1503	0.1565	0.7126	0.016
591	6	1	0.0218	0.005	0.1588	0.1796	0.9451	0.016
592	6	2	0.0218	0.005	0.0853	0.1099	0.1694	0.016
593	6	2	0.0218	0.005	0.1128	0.1640	0.3437	0.016
594	6	2	0.0218	0.005	0.1315	0.2134	0.5053	0.016
595	6	2	0.0218	0.005	0.1515	0.2508	0.7169	0.016
596	6	2	0.0218	0.005	0.1703	0.2919	0.9133	0.016
597	6	2	0.0218	0.005	0.1815	0.3367	1.1410	0.016
598	6	3	0.0218	0.005	0.0865	0.1353	0.1617	0.016
599	6	3	0.0218	0.005	0.1128	0.2225	0.3264	0.016
600	6	3	0.0218	0.005	0.1315	0.2813	0.4859	0.016
601	6	3	0.0218	0.005	0.1540	0.3606	0.7211	0.016
602	6	3	0.0218	0.005	0.1703	0.4382	0.9632	0.016
603	6	3	0.0218	0.005	0.1815	0.4950	1.1507	0.016
604	6	3	0.0218	0.005	0.1915	0.5250	1.2904	0.016
605	6	4	0.0218	0.005	0.0878	0.1565	0.1644	0.016
606	6	4	0.0218	0.005	0.1140	0.2709	0.3225	0.016
607	6	4	0.0218	0.005	0.1315	0.3606	0.4959	0.016
608	6	4	0.0218	0.005	0.1503	0.4661	0.7072	0.016
609	6	4	0.0218	0.005	0.1703	0.5561	0.9289	0.016
610	6	4	0.0218	0.005	0.1815	0.6214	1.1164	0.016
611	6	4	0.0218	0.005	0.1915	0.6912	1.2958	0.016
612	6	4	0.0218	0.005	0.1978	0.7277	1.4189	0.016
613	6	4	0.0218	0.005	0.1990	0.7654	1.5309	0.016
614	6	5	0.0218	0.005	0.0890	0.1640	0.1643	0.016
615	6	5	0.0218	0.005	0.1128	0.3138	0.3312	0.016
616	6	5	0.0218	0.005	0.1328	0.4113	0.4840	0.016
617	6	5	0.0218	0.005	0.1515	0.5250	0.6890	0.016
618	6	5	0.0218	0.005	0.1690	0.6384	0.9197	0.016
619	6	5	0.0218	0.005	0.1815	0.7465	1.1319	0.016
620	6	5	0.0218	0.005	0.1903	0.8043	1.2847	0.016
621	6	5	0.0218	0.005	0.1953	0.8647	1.4208	0.016
622	6	5	0.0218	0.005	0.2603	0.8855	1.4901	0.016
623	6	5	0.0218	0.005	0.2103	0.9714	1.7368	0.016
624	6	1	0.0235	0.02	0.0703	0.0681	0.1721	0.016
625	6	1	0.0235	0.02	0.0928	0.1040	0.3357	0.016
626	6	1	0.0235	0.02	0.1090	0.1222	0.5076	0.016
627	6	1	0.0235	0.02	0.1265	0.1422	0.7304	0.016
628	6	1	0.0235	0.02	0.1263	0.1717	0.9372	0.016

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
629	6	2	0.0235	0.02	0.0765	0.0983	0.1807	0.016
630	6	2	0.0235	0.02	0.0953	0.1493	0.3454	0.016
631	6	2	0.0235	0.02	0.1128	0.1878	0.5129	0.016
632	6	2	0.0235	0.02	0.1253	0.2317	0.6977	0.016
633	6	2	0.0235	0.02	0.1378	0.2709	0.9266	0.016
634	6	2	0.0235	0.02	0.1503	0.3027	1.1269	0.016
635	6	3	0.0235	0.02	0.0753	0.1222	0.1817	0.016
636	6	3	0.0235	0.02	0.0940	0.1961	0.3454	0.016
637	6	3	0.0235	0.02	0.1140	0.2508	0.5116	0.016
638	6	3	0.0235	0.02	0.1278	0.3138	0.7251	0.016
639	6	3	0.0235	0.02	0.1415	0.3606	0.9326	0.016
640	6	3	0.0235	0.02	0.1515	0.4113	1.1767	0.016
641	6	4	0.0235	0.02	0.0703	0.1353	0.1671	0.016
642	6	4	0.0235	0.02	0.0940	0.2317	0.3415	0.016
643	6	4	0.0235	0.02	0.1140	0.3138	0.5099	0.016
644	6	4	0.0235	0.02	0.1265	0.3729	0.6867	0.016
645	6	4	0.0235	0.02	0.1390	0.4382	0.9332	0.016
646	6	4	0.0235	0.02	0.1515	0.5250	1.1464	0.016
647	6	4	0.0235	0.02	0.1553	0.5561	1.3215	0.016
648	6	5	0.0235	0.02	0.0740	0.1493	0.1629	0.016
649	6	5	0.0235	0.02	0.0940	0.2709	0.3483	0.016
650	6	5	0.0235	0.02	0.1090	0.3367	0.4860	0.016
651	6	5	0.0235	0.02	0.1290	0.4464	0.7072	0.016
652	6	5	0.0235	0.02	0.1415	0.5250	0.9232	0.016
653	6	5	0.0235	0.02	0.1490	0.6047	1.1297	0.016
654	6	5	0.0235	0.02	0.1590	0.6557	1.3115	0.016
655	6	5	0.0235	0.02	0.1628	0.6912	1.4189	0.016
656	6	5	0.0235	0.02	0.1653	0.7277	1.5320	0.016
657	6	1	0.0433	0.005	0.1140	0.0875	0.1556	0.016
658	6	1	0.0433	0.005	0.1490	0.1353	0.3231	0.016
659	6	1	0.0433	0.005	0.1715	0.1717	0.4969	0.016
660	6	1	0.0433	0.005	0.1915	0.2317	0.6977	0.016
661	6	1	0.0433	0.005	0.2125	0.2919	1.0573	0.016
662	6	2	0.0433	0.005	0.1140	0.1394	0.1700	0.016
663	6	2	0.0433	0.005	0.1465	0.2317	0.3539	0.016
664	6	2	0.0433	0.005	0.1715	0.2919	0.5053	0.016
665	6	2	0.0433	0.005	0.1915	0.3606	0.6973	0.016
666	6	2	0.0433	0.005	0.2090	0.4246	0.9196	0.016
667	6	2	0.0433	0.005	0.2290	0.4804	1.1361	0.016
668	6	2	0.0433	0.005	0.2390	0.5099	1.2946	0.016

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
669	6	3	0.0433	0.005	0.1190	0.1640	0.1719	0.016
670	6	3	0.0433	0.005	0.1503	0.2919	0.3362	0.016
671	6	3	0.0433	0.005	0.1690	0.3606	0.4646	0.016
672	6	3	0.0433	0.005	0.1903	0.4661	0.6622	0.016
673	6	3	0.0433	0.005	0.2128	0.5720	0.8971	0.016
674	6	3	0.0433	0.005	0.2290	0.6557	1.1077	0.016
675	6	3	0.0433	0.005	0.2390	0.7093	1.2813	0.016
676	6	3	0.0433	0.005	0.2478	0.7465	1.4198	0.016
677	6	3	0.0433	0.005	0.2553	0.7847	1.5502	0.016
678	6	4	0.0433	0.005	0.1240	0.1640	0.1640	0.016
679	6	4	0.0433	0.005	0.1515	0.3367	0.3434	0.016
680	6	4	0.0433	0.005	0.1715	0.4520	0.4897	0.016
681	6	4	0.0433	0.005	0.1915	0.5882	0.6865	0.016
682	6	4	0.0433	0.005	0.2178	0.7277	0.9238	0.016
683	6	4	0.0433	0.005	0.2290	0.8443	1.1152	0.016
684	6	4	0.0433	0.005	0.2390	0.8855	1.2460	0.016
685	6	4	0.0433	0.005	0.2478	0.9495	1.3876	0.016
686	6	4	0.0433	0.005	0.2540	0.9936	1.5186	0.016
687	6	4	0.0433	0.005	0.2915	1.0390	1.7302	0.016
688	6	4	0.0433	0.005	0.2715	1.0621	1.8276	0.016
689	6	5	0.0433	0.005	0.1140	0.1640	0.1640	0.016
690	6	5	0.0433	0.005	0.1453	0.3251	0.3252	0.016
691	6	5	0.0433	0.005	0.1665	0.4661	0.4707	0.016
692	6	5	0.0433	0.005	0.1878	0.6557	0.6752	0.016
693	6	5	0.0433	0.005	0.2065	0.8241	0.9016	0.016
694	6	5	0.0433	0.005	0.2240	0.9495	1.0848	0.016
695	6	5	0.0433	0.005	0.2403	1.0856	1.3267	0.016
696	6	5	0.0433	0.005	0.2478	1.1824	1.5076	0.016
697	6	5	0.0433	0.005	0.2565	1.2074	1.6187	0.016
698	6	5	0.0433	0.005	0.2628	1.2584	1.7388	0.016
699	6	5	0.0433	0.005	0.2678	1.2843	1.7942	0.016
700	6	5	0.0433	0.005	0.2690	1.3106	1.8510	0.016
701	6	1	0.0436	0.02	0.0915	0.0928	0.1655	0.016
702	6	1	0.0436	0.02	0.1228	0.1353	0.3488	0.016
703	6	1	0.0436	0.02	0.1378	0.1565	0.5050	0.016
704	6	1	0.0436	0.02	0.1565	0.1878	0.7128	0.016
705	6	1	0.0436	0.02	0.1675	0.2225	1.0267	0.016
706	6	2	0.0436	0.02	0.0915	0.1222	0.1539	0.016
707	6	2	0.0436	0.02	0.1215	0.2047	0.3268	0.016
708	6	2	0.0436	0.02	0.1340	0.2607	0.4832	0.016

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
709	6	2	0.0436	0.02	0.1553	0.3027	0.7010	0.016
710	6	2	0.0436	0.02	0.1690	0.3367	0.9087	0.016
711	6	2	0.0436	0.02	0.1815	0.3729	1.1383	0.016
712	6	3	0.0436	0.02	0.0915	0.1493	0.1629	0.016
713	6	3	0.0436	0.02	0.1240	0.2709	0.3436	0.016
714	6	3	0.0436	0.02	0.1390	0.3606	0.4959	0.016
715	6	3	0.0436	0.02	0.1565	0.4520	0.7229	0.016
716	6	3	0.0436	0.02	0.1715	0.5099	0.9480	0.016
717	6	3	0.0436	0.02	0.1848	0.5250	1.1132	0.016
718	6	3	0.0436	0.02	0.1940	0.5561	1.3215	0.016
719	6	4	0.0436	0.02	0.0965	0.1640	0.1719	0.016
720	6	4	0.0436	0.02	0.1240	0.3138	0.3354	0.016
721	6	4	0.0436	0.02	0.1365	0.4113	0.4887	0.016
722	6	4	0.0436	0.02	0.1565	0.5250	0.6890	0.016
723	6	4	0.0436	0.02	0.1690	0.6214	0.9352	0.016
724	6	4	0.0436	0.02	0.1840	0.6557	1.1077	0.016
725	6	4	0.0436	0.02	0.1940	0.6912	1.2794	0.016
726	6	4	0.0436	0.02	0.2003	0.7277	1.4189	0.016
727	6	4	0.0436	0.02	0.2065	0.7654	1.5309	0.016
728	6	5	0.0436	0.02	0.0965	0.1640	0.1640	0.016
729	6	5	0.0436	0.02	0.1253	0.3367	0.3423	0.016
730	6	5	0.0436	0.02	0.1365	0.4661	0.4877	0.016
731	6	5	0.0436	0.02	0.1540	0.5882	0.6706	0.016
732	6	5	0.0436	0.02	0.1690	0.7277	0.8995	0.016
733	6	5	0.0436	0.02	0.1815	0.8043	1.0962	0.016
734	6	5	0.0436	0.02	0.1940	0.8855	1.2968	0.016
735	6	5	0.0436	0.02	0.1990	0.8855	1.3805	0.016
736	6	5	0.0436	0.02	0.2078	0.9065	1.4947	0.016
737	6	5	0.0436	0.02	0.2115	0.9278	1.5836	0.016
738	6	5	0.0436	0.02	0.2265	0.9714	1.7955	0.016
739	6	1	0.0613	0.005	0.1390	0.1159	0.1934	0.016
740	6	1	0.0613	0.005	0.1653	0.1565	0.3283	0.016
741	6	1	0.0613	0.005	0.1903	0.2134	0.4947	0.016
742	6	1	0.0613	0.005	0.2115	0.2508	0.7028	0.016
743	6	1	0.0613	0.005	0.2365	0.2813	0.9027	0.016
744	6	1	0.0613	0.005	0.2438	0.2919	1.0962	0.016
745	6	2	0.0613	0.005	0.1290	0.1422	0.1527	0.016
746	6	2	0.0613	0.005	0.1640	0.2508	0.3332	0.016
747	6	2	0.0613	0.005	0.1890	0.3251	0.4744	0.016
748	6	2	0.0613	0.005	0.2165	0.4246	0.7059	0.016

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
749	6	2	0.0613	0.005	0.2378	0.4804	0.9186	0.016
750	6	2	0.0613	0.005	0.2540	0.5099	1.1145	0.016
751	6	2	0.0613	0.005	0.2703	0.5250	1.2904	0.016
752	6	3	0.0613	0.005	0.1340	0.1796	0.1796	0.016
753	6	3	0.0613	0.005	0.1640	0.3027	0.3164	0.016
754	6	3	0.0613	0.005	0.1878	0.4113	0.4629	0.016
755	6	3	0.0613	0.005	0.2128	0.5250	0.6472	0.016
756	6	3	0.0613	0.005	0.2378	0.6557	0.8969	0.016
757	6	3	0.0613	0.005	0.2540	0.7277	1.1260	0.016
758	6	3	0.0613	0.005	0.2678	0.7654	1.2904	0.016
759	6	3	0.0613	0.005	0.2778	0.7847	1.4061	0.016
760	6	3	0.0613	0.005	0.2928	0.8241	1.5896	0.016
761	6	4	0.0613	0.005	0.1340	0.1796	0.1796	0.016
762	6	4	0.0613	0.005	0.1715	0.3606	0.3606	0.016
763	6	4	0.0613	0.005	0.1940	0.4950	0.5006	0.016
764	6	4	0.0613	0.005	0.2153	0.6384	0.6794	0.016
765	6	4	0.0613	0.005	0.2403	0.7847	0.9006	0.016
766	6	4	0.0613	0.005	0.2540	0.8855	1.0989	0.016
767	6	4	0.0613	0.005	0.2690	0.9714	1.2852	0.016
768	6	4	0.0613	0.005	0.2865	1.0162	1.4681	0.016
769	6	4	0.0613	0.005	0.2978	1.1093	1.6813	0.016
770	6	4	0.0613	0.005	0.3040	1.1578	1.7962	0.016
771	6	4	0.0613	0.005	0.3065	1.1824	1.8918	0.016
772	6	4	0.0613	0.005	0.3065	1.1824	1.9479	0.016
773	6	5	0.0613	0.005	0.1303	0.0983	0.0983	0.016
774	6	5	0.0613	0.005	0.1640	0.3251	0.3251	0.016
775	6	5	0.0613	0.005	0.1890	0.4804	0.4804	0.016
776	6	5	0.0613	0.005	0.2153	0.6733	0.6757	0.016
777	6	5	0.0613	0.005	0.2378	0.8855	0.8992	0.016
778	6	5	0.0613	0.005	0.2540	1.0390	1.0833	0.016
779	6	5	0.0613	0.005	0.2678	1.1578	1.2676	0.016
780	6	5	0.0613	0.005	0.2765	1.2584	1.4224	0.016
781	6	5	0.0613	0.005	0.2865	1.3106	1.5423	0.016
782	6	5	0.0613	0.005	0.3028	1.3913	1.7280	0.016
783	6	5	0.0613	0.005	0.3053	1.4189	1.8301	0.016
784	6	5	0.0613	0.005	0.3128	1.4467	1.8987	0.016
785	6	1	0.0623	0.02	0.1065	0.1040	0.1635	0.016
786	6	1	0.0623	0.02	0.1353	0.1493	0.3133	0.016
787	6	1	0.0623	0.02	0.1578	0.1878	0.4905	0.016
788	6	1	0.0623	0.02	0.1778	0.2225	0.7175	0.016

Test No.	W	N	S_x	S	y	Q_c	Q_a	n
789	6	1	0.0623	0.02	0.1963	0.2607	1.0650	0.016
790	6	2	0.0623	0.02	0.1078	0.1353	0.1643	0.016
791	6	2	0.0623	0.02	0.1353	0.2508	0.3283	0.016
792	6	2	0.0623	0.02	0.1578	0.2919	0.4715	0.016
793	6	2	0.0623	0.02	0.1765	0.3606	0.7091	0.016
794	6	2	0.0623	0.02	0.1928	0.3982	0.9232	0.016
795	6	2	0.0623	0.02	0.2153	0.4382	1.2036	0.016
796	6	3	0.0623	0.02	0.1065	0.1565	0.1579	0.016
797	6	3	0.0623	0.02	0.1353	0.3138	0.3275	0.016
798	6	3	0.0623	0.02	0.1578	0.4113	0.4794	0.016
799	6	3	0.0623	0.02	0.1753	0.4804	0.6765	0.016
800	6	3	0.0623	0.02	0.1915	0.5404	0.9133	0.016
801	6	3	0.0623	0.02	0.2103	0.5882	1.1286	0.016
802	6	3	0.0623	0.02	0.2253	0.6557	1.4212	0.016
803	6	4	0.0623	0.02	0.1015	0.1493	0.1493	0.016
804	6	4	0.0623	0.02	0.1340	0.3251	0.3256	0.016
805	6	4	0.0623	0.02	0.1565	0.4520	0.4675	0.016
806	6	4	0.0623	0.02	0.1765	0.6047	0.6821	0.016
807	6	4	0.0623	0.02	0.1928	0.6733	0.8958	0.016
808	6	4	0.0623	0.02	0.2078	0.7465	1.0950	0.016
809	6	4	0.0623	0.02	0.2203	0.7847	1.2651	0.016
810	6	4	0.0623	0.02	0.2290	0.8241	1.4288	0.016
811	6	4	0.0623	0.02	0.2378	0.8647	1.6302	0.016
812	6	5	0.0623	0.02	0.1065	0.1565	0.1565	0.016
813	6	5	0.0623	0.02	0.1340	0.3138	0.3138	0.016
814	6	5	0.0623	0.02	0.1565	0.4661	0.4663	0.016
815	6	5	0.0623	0.02	0.1765	0.6733	0.6838	0.016
816	6	5	0.0623	0.02	0.1940	0.8241	0.8969	0.016
817	6	5	0.0623	0.02	0.2103	0.8855	1.0651	0.016
818	6	5	0.0623	0.02	0.2228	0.9495	1.2522	0.016
819	6	5	0.0623	0.02	0.2290	0.9936	1.4049	0.016
820	6	5	0.0623	0.02	0.2378	1.0390	1.5489	0.016
821	6	5	0.0623	0.02	0.2403	1.0621	1.6503	0.016
822	6	5	0.0623	0.02	0.2553	1.1334	1.8988	0.016

Appendix B. Photographs

Figure B-1 Capture Reservoir and Weir (120 Degree)

Figure B-2 Bypass Reservoir and Weir (120 Degree)

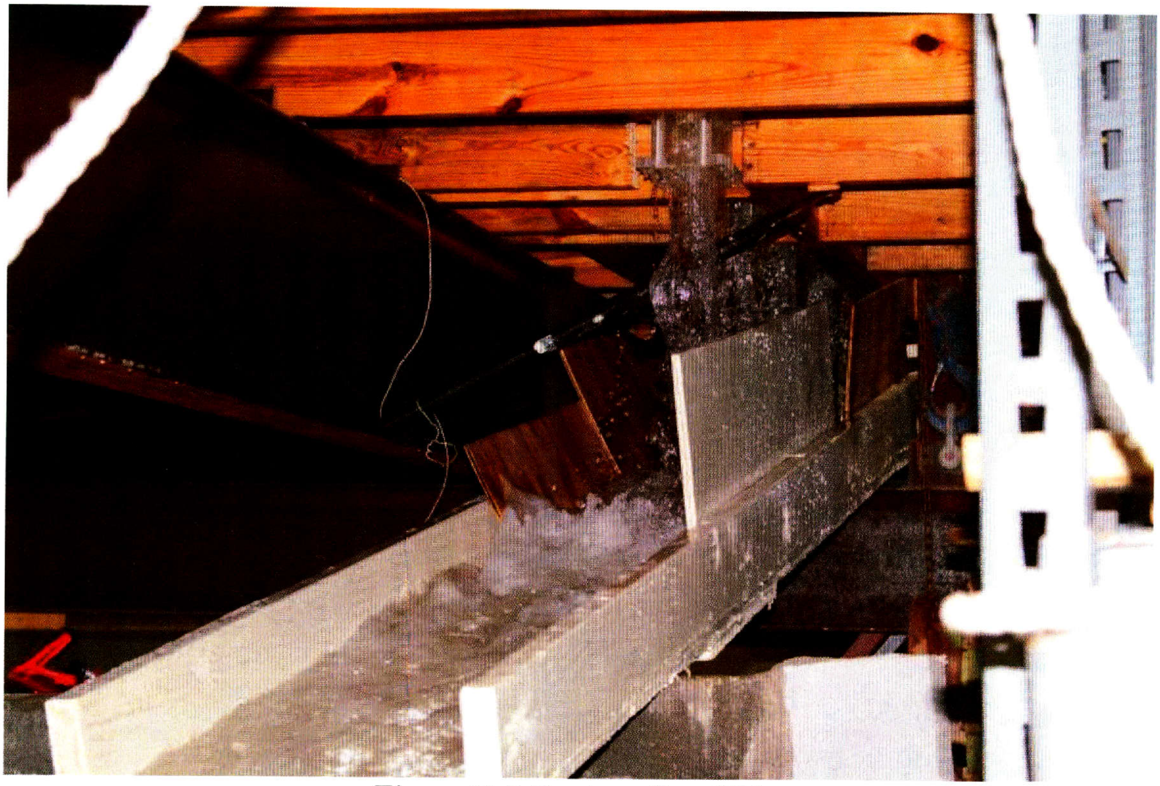


Figure B-3 Capture Box Slide

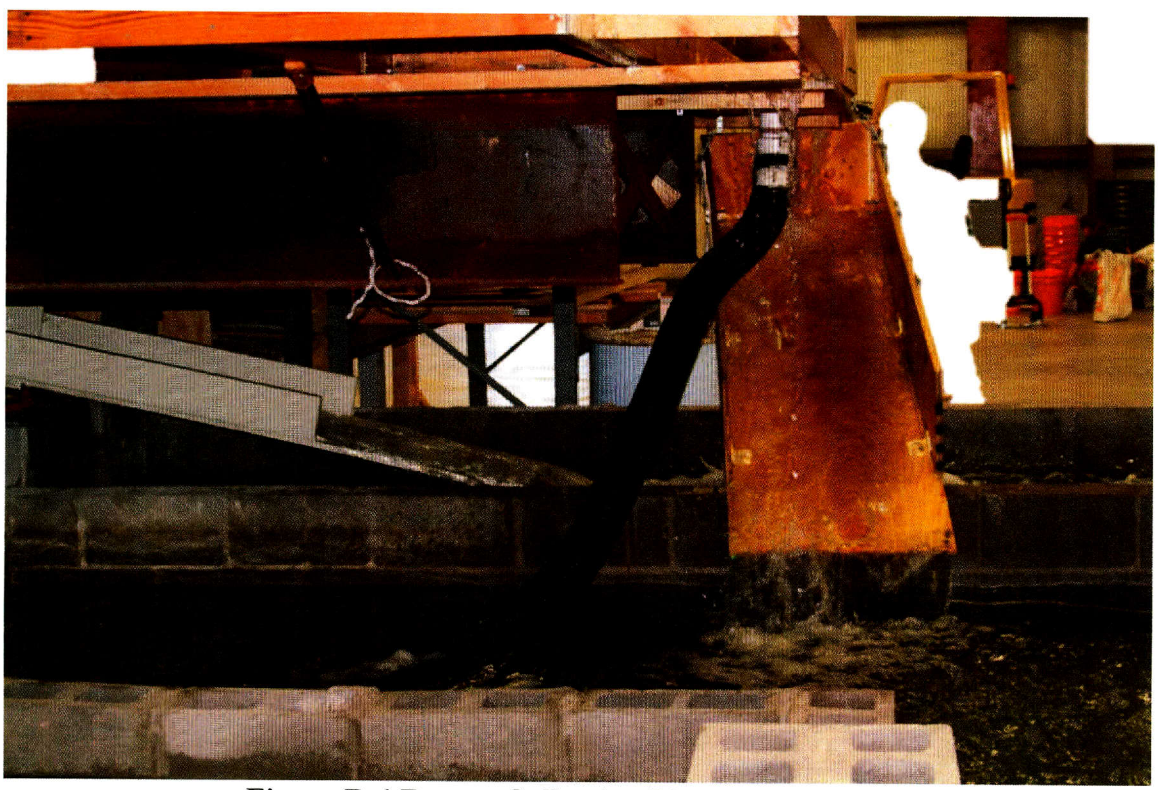


Figure B-4 Bypass Collection Pipe and Box Slide

Figure B-5 Capture Slide Modification

Figure B-6 Flow Profile (Looking Upstream) with 5-open 4in. × 8in. Drains at 4% Cross Slope and 1.0% Longitudinal Slope with Q = 2.25 Revolutions at Head Box Valve

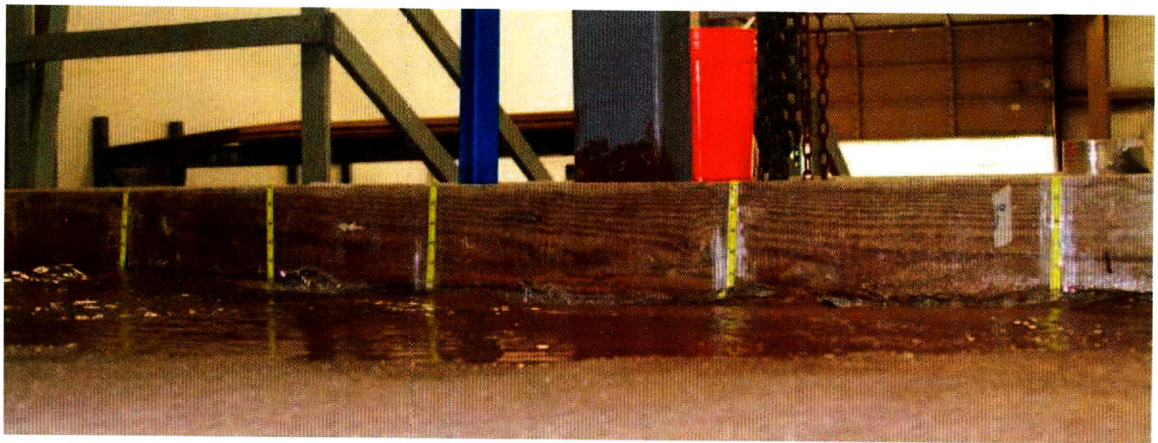


Figure B-7 Flow Depth against Curb with 5-open 4in. × 8in. Drains at 4% Cross Slope and 0.5% Longitudinal Slope with Q = 1.25 Revolutions at Head Box Valve

Figure B-8 Flow Profile (Looking Downstream) with 2-open 4in. × 8in. Drains at 4% Cross Slope and 0.1% Longitudinal Slope with Q = 1.5 Revolutions at Head Box Valve

Figure B-9 Flow Pattern over Drains (Looking Downstream)

Figure B-10 Flow Depth against Curb Flow with 2-open 4in. × 8in. Drains at 4% Cross Slope and 0.1% Longitudinal Slope with Q = 1.5 Revolutions at Head Box Valve

Figure B-11 Flow (Looking Upstream) with 2-open 4in. × 8in. Drains at 4% Cross Slope and 0.1% Longitudinal Slope with Q = 1.5 Revolutions at Head Box Valve

Figure B-12 6in. × 8in. Drain Placement

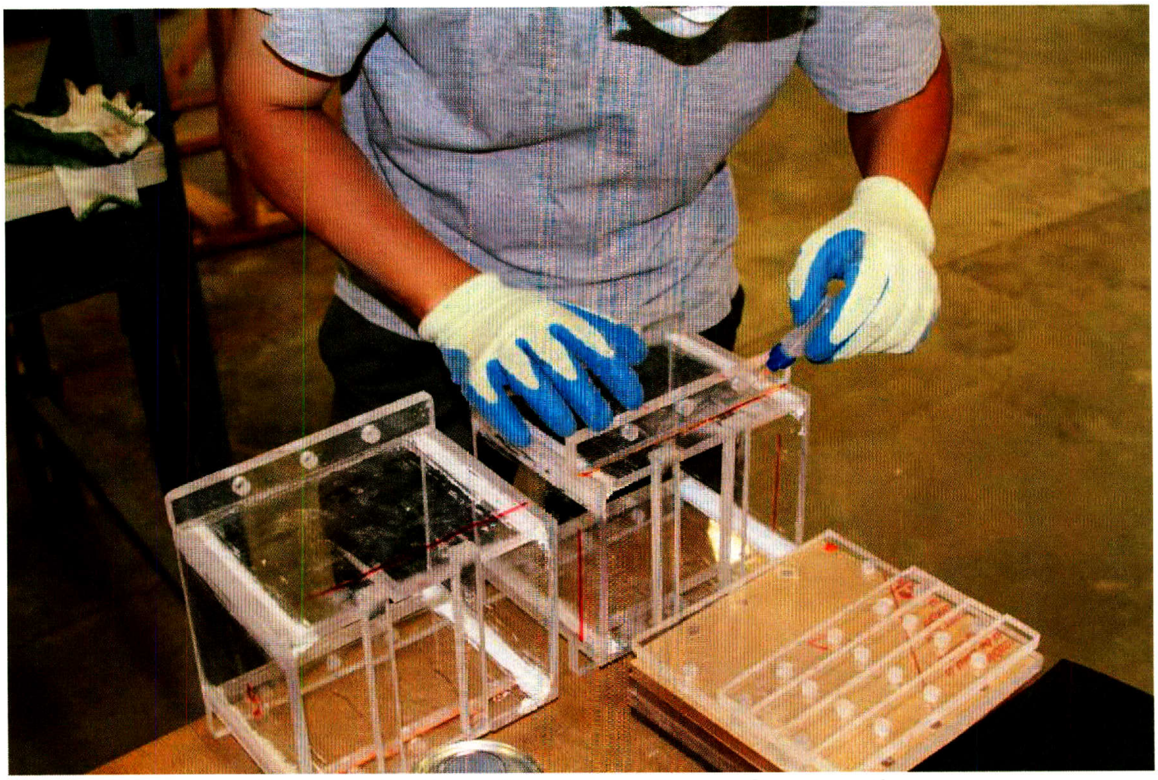


Figure B-13 6in. × 8in. Drain Flange Construction

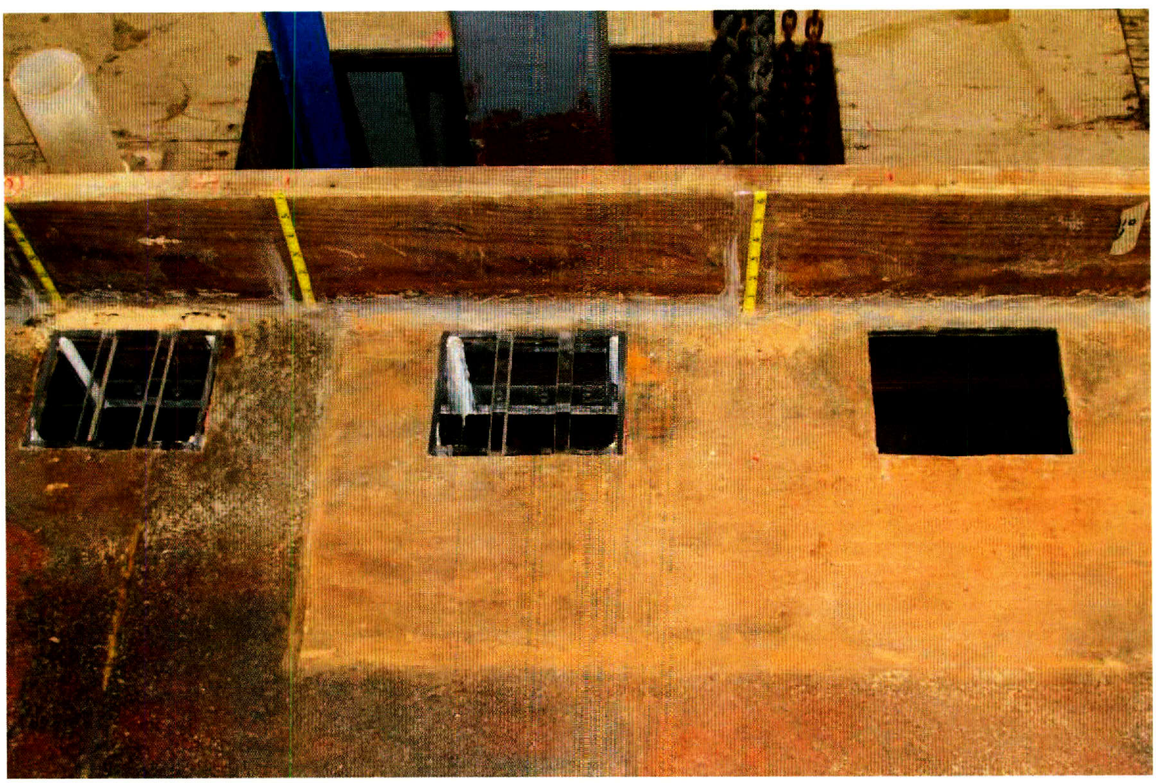


Figure B-14 6in. × 8in. Drain Installation

Figure B-15 Finished 6in. × 8in. Drain Installment

Figure B-16 Flow with 4-open 6in. × 8in. Drains at 2% Cross Slope and 0.5% Longitudinal Slope with Q = 1.0 Revolutions at Head Box Valve

Figure B-17 Flow from the Right (upstream) into Drains 1 (top-left), 2 (top-right), 3 (bottom-left) and 4 (bottom-right) with 4-open 6in. × 8in. Drains at 2% Cross Slope and 0.5% Longitudinal Slope with Q = 1.0 Revolutions at Head Box Valve

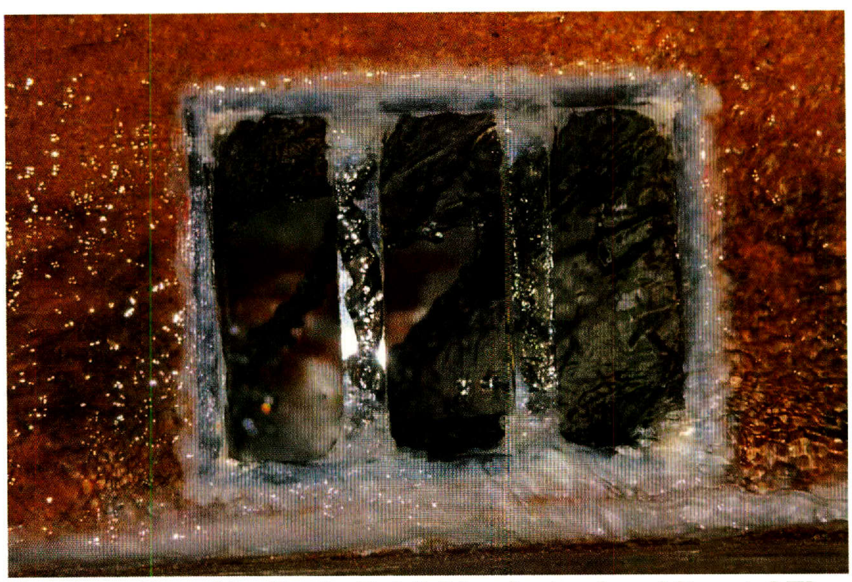


Figure B-18 Flow into 6in.× 8in. Drain Exhibiting Lateral and Frontal Flow Interception

Figure B-19 Flow with 4-open 6in. × 8in. Drains at 6% Cross Slope and 0.5% Longitudinal Slope with Q = 1.25 Revolutions at Head Box Valve

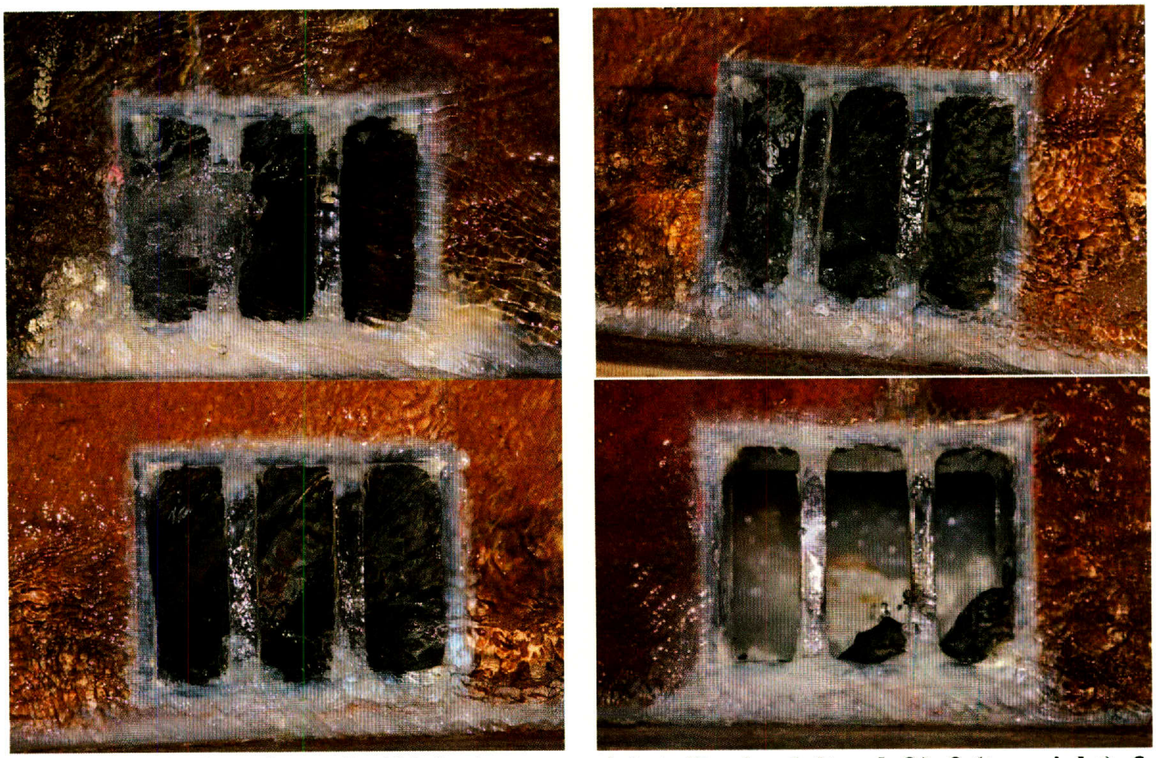


Figure B-20 Flow from the Right (upstream) into Drains 1 (top-left), 2 (top-right), 3 (bottom-left) and 4 (bottom-right) with 4-open 6in. × 8in. Drains at 6% Cross Slope and 0.5% Longitudinal Slope with Q = 1.25 Revolutions at Head Box Valve

Appendix C. Hydraulic Effect of Drain Spacing

Introduction

After studying the hydraulic performance of rectangular scupper drains and analyzing the ability of existing design equations to predict this performance, a new equation was developed that more accurately predicts capture discharge. This equation, Equation 4.4 in this report's Chapter 4, is shown here. The new equation indicates that capture discharge is a function of the magnitude of approach flow, Manning's coefficient, and the cross and longitudinal slopes. Capture discharge is also proportional to the product of the number of drains open and the sum of the drain width and drain length. A nonlinear regression analysis using the IBM SPSS Statistic Editor showed that the effects of drain width and the number of drains open are not significant.

$$Q_c = 1.712N(nQ_a)^{9/16}(L+W)\frac{S_x^{0.3122}}{S_0^{0.1770}} \tag{4.4}$$

One other variable also warranted further investigation. Although test runs were performed at many combinations of cross and longitudinal slope for one to five open drains, the initial study did not include any runs investigating the effect of increased spacing on the hydraulic performance of the drains. Additional runs were performed testing drains as close together as 1.5 ft and as far apart as 6 ft. Table C-1 presents all the possible combinations of open drains and corresponding spacing values (measured from the center of the first open drain to the center of the next open downstream drain). The previous study found that each drain captured the same amount of flow, so the only way to increase the performance (amount of flow captured) was to increase the number of drains. The purpose of these additional runs was to determine the effect of spacing on the hydraulic performance of rectangular scupper drains.

Table C-2 Spacing Options

Drains open	Spacing (ft)
1, 2	1.5′
1, 3	3.0′
1, 4	4.5′
1, 5	6.0′
1, 3, 5	3.0′

For each combination of drains, various runs were performed for a number of combinations of cross slope and longitudinal slope. A minimum of 5 runs were performed for each combination of cross and longitudinal slope (15 total) with 5 possible combinations of drains open. This amounted to 464 total test runs performed to test the effects of spacing on hydraulic drain performance. All combinations of cross slope and longitudinal slope tested are shown in Table C-2.

Table C-3 Cross and Longitudinal Slopes Tested

Cross	Longitudinal
2	0.1
2	0.5
2	1
2	2
2	4
4	0.1
4	0.5
4	1
4	2
4	4
6	0.1
6	0.5
6	1
6	2
6	4

Data

The previous study found that each drain captured the same amount of flow, so the only way to increase the performance (amount of flow captured) was to increase the number of drains. While a slight increase in the amount of captured flow was observed for drains spaced farther than 1.5 ft apart, this trend did not continue when the drains were spaced 3 ft apart or more. In fact, drains spaced 3 ft, 4.5 ft, and 6 ft apart performed almost identically for each combination of cross and longitudinal slope tested. Figures C-1, C-2, and C-3 show the measured amount of flow captured by the drains compared to the amount of flow approaching the drains. Since all combinations of flow demonstrated similar patterns, only the 2% longitudinal slope for the 2%, 4%, and 6% cross slope runs are shown here. Plots of all data can be found at the end of this appendix.

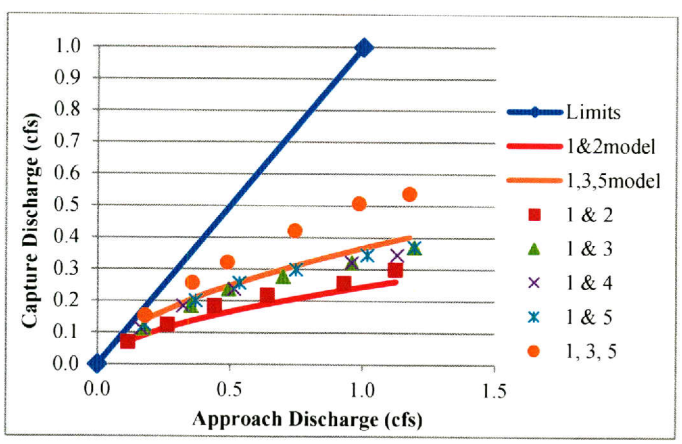


Figure C-21 Approach vs. Capture Discharge for 2% Cross Slope, 2% Longitudinal Slope

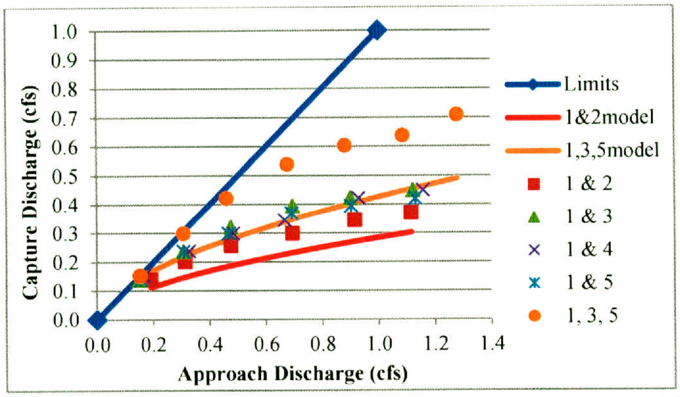


Figure C-22 Approach vs. Capture Discharge for 4% Cross Slope, 2% Longitudinal Slope

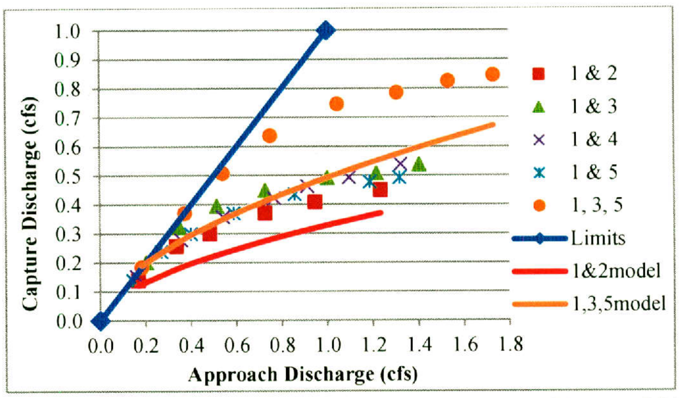


Figure C-23 Approach vs. Capture Discharge for 6% Cross Slope, 2% Longitudinal Slope

After all of the runs were completed, the measured approach flow values were used to calculate the captured flow using Equation 4.4. Figures C-1, C-2, and C-3 show both the measured and modeled flow values for three of the combinations of slopes tested. The red line indicates the modeled values of flow for when two drains are open (spacing values 1.5 ft, 3 ft, 4.5 ft, and 6 ft) while the orange line represents the modeled values of captured flow when three drains are open (drains 1, 3, and 5). Only one line is shown for all of the combinations of two drains open because the values were so similar they were almost indistinguishable.

Methodology

Once the modeled values of flow had been calculated, several calculations were performed to determine the quality of the model. The four categories of error considered were the root mean square error, gamma values, magnitude of error, and residuals.

Root Mean Squared Error

The root mean squared error (RMSE) is used to measure the difference between values predicted by the model equation and the observed values. The equation used to calculate the value of RMSE is shown as Equation C.1.

$$RMSE = \sqrt{\frac{\Sigma(Q_{capture,model} - Q_{capture,measured})^2}{N}} \quad (C.1)$$

The values of RMSE were considered insignificant given the large scale of the physical model.

Gamma Values

Another criterion for determining the effectiveness of the model equation was to examine the importance of the number of drains open (the variable N in Equation 4). The significance of this variable was tested by raising the variable N to a power gamma (γ). The value of gamma was found by using the Solver function in Microsoft Excel to minimize the value of RMSE. The values of gamma obtained by analyzing the new set of data and their corresponding values of RMSE are shown in Table C-3.

Table C-4 Gamma and RMSE Values

Drains open	Spacing (ft)	N	RMSE (γ=1) (cfs)	RMSE ($\gamma \neq 1$) (cfs)	γ
1, 2	1.5	2	0.04806	0.03997	1.134
1, 3	3	2	0.09371	0.05201	1.357
1, 4	4.5	2	0.08890	0.04946	1.339
1, 5	6	2	0.18453	0.13797	1.412
1, 3, 5	3_3	3	0.18564	0.13201	1.186
All data	N/A	1-5	0.13410	0.06349	1.202

The previous data set examining the effect of the number of drains open on hydraulic performance produced a gamma value of 0.867 with a corresponding RMSE value of 0.099. The RMSE corresponding to a gamma value of 1 was 0.122. This difference was considered insignificant considering the large scale of the model. For the new data, all gamma values resulted in a N^{γ} value within 30% of its corresponding value of N (2 or 3). Due to the highly unpredictable nature of hydraulics, this magnitude of error is insignificant. Estimates on the correct order of magnitude are sufficient to provide useable estimates of discharge values.

RMSE values found for the new data set were of a similar magnitude for all drain spacing options. While the magnitudes of gamma were larger than the values previously found for the 6in. x 8in. drains (indicating that spacing the drains farther apart did have some effect), this difference was not large enough to be considered significant. The analysis of both the magnitude of error and residual values were performed only for the calculated capture flow values corresponding to the original form of Equation 4.4 where gamma is equal to 1.

Magnitude of Error

The error of the captured flow values modeled by Equation 4.4 was calculated as the difference between the calculated values of captured flow and the measured capture flow normalized by the value of measured flow. This error value was used to determine whether the model overpredicts or underpredicts the amount of flow captured for a given magnitude of approach flow. The equation used to calculate the magnitude of error is shown as Equation C.2.

$$Error = \frac{Q_{capture,model} - Q_{capture,measured}}{Q_{capture,measured}} \qquad (C.2)$$

Although the error did increase with increasing values of approach flow as expected, no trend was observed between the spacing of the drains and the magnitude of error. The model underpredicts the amount of flow captured for all combinations of open drains and the number of samples underpredicted and the magnitude of underprediction was similar for all values of drain spacing. Table C-4 shows the percent of underpredicted values given two different tolerance levels. A plot of the magnitude of error values versus their corresponding captured flow values is shown in Figure C-4.

Table C-5 Percent of Samples Underpredicted by Equation 4.4

	With tolerance of 0	With tolerance of 0.1
1, 2- 1.5' spacing	69%	55%
1, 3- 3' spacing	95%	82%
1, 4- 4.5' spacing	92%	78%
1, 5- 6' spacing	92%	79%
1, 3, 5- 3' spacing (N=3)	70%	71%

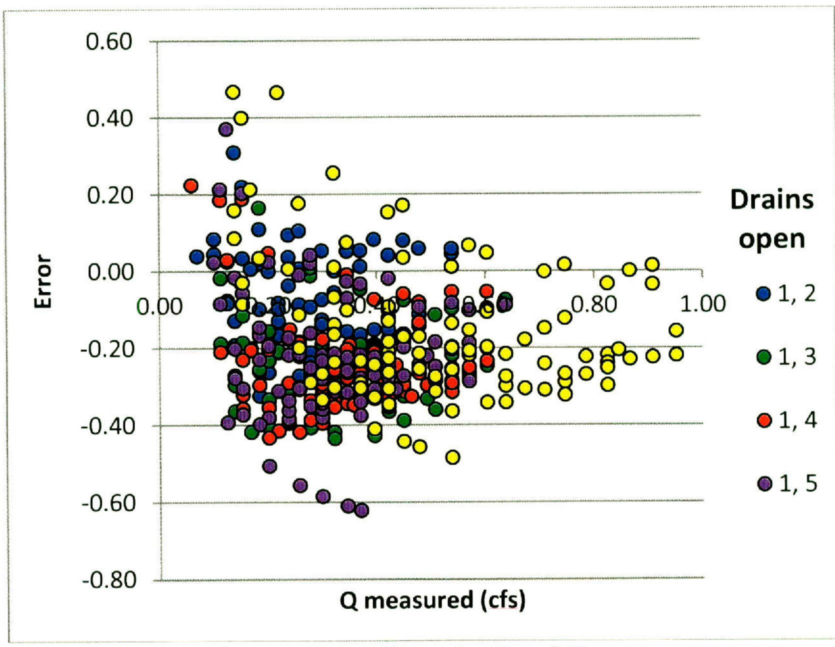


Figure C-24 Magnitude of Error

Residuals

Residuals are another measure used to quantify the magnitude of the difference between the measured value of captured flow and the predicted value obtained from the model equation (see Figure C-5). A residual is defined as the difference between the estimated function value (found by using Equation 4.4) and the sample value measured during data collection, scaled by the measured value. By scaling the difference between these two values, a better perspective of the magnitude of the error in comparison to the measured value is achieved. The equation used to calculated residuals is shown as Equation C.3.

$$Residual = \frac{Q_{capture,model} - Q_{capture,measured}}{Q_{capture,measured}} \qquad (C.3)$$

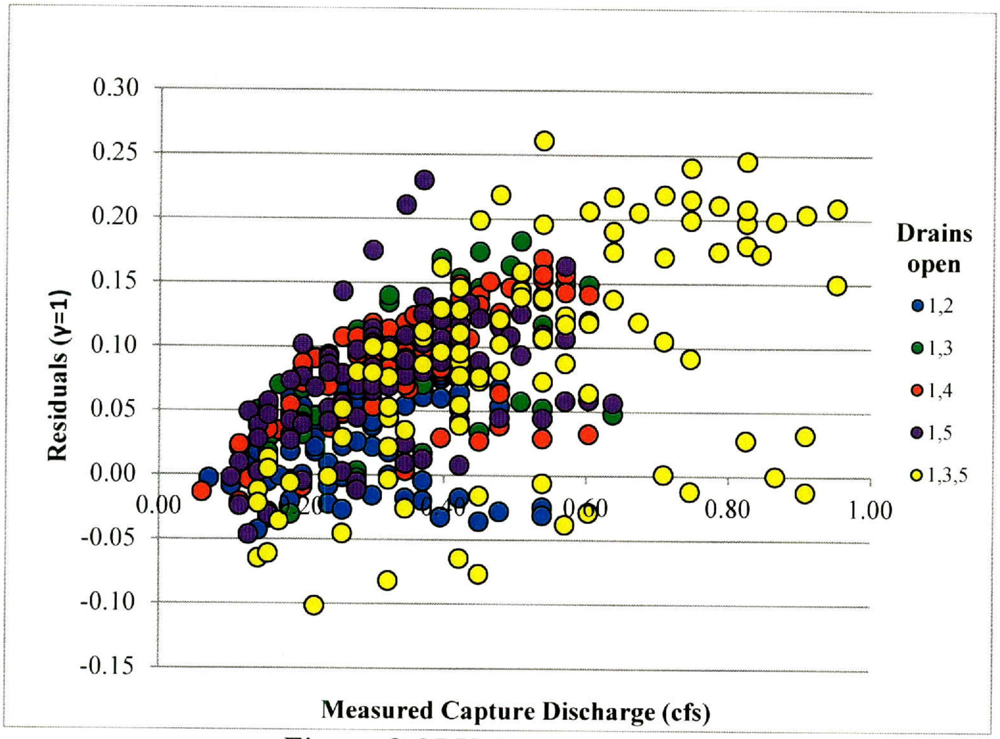
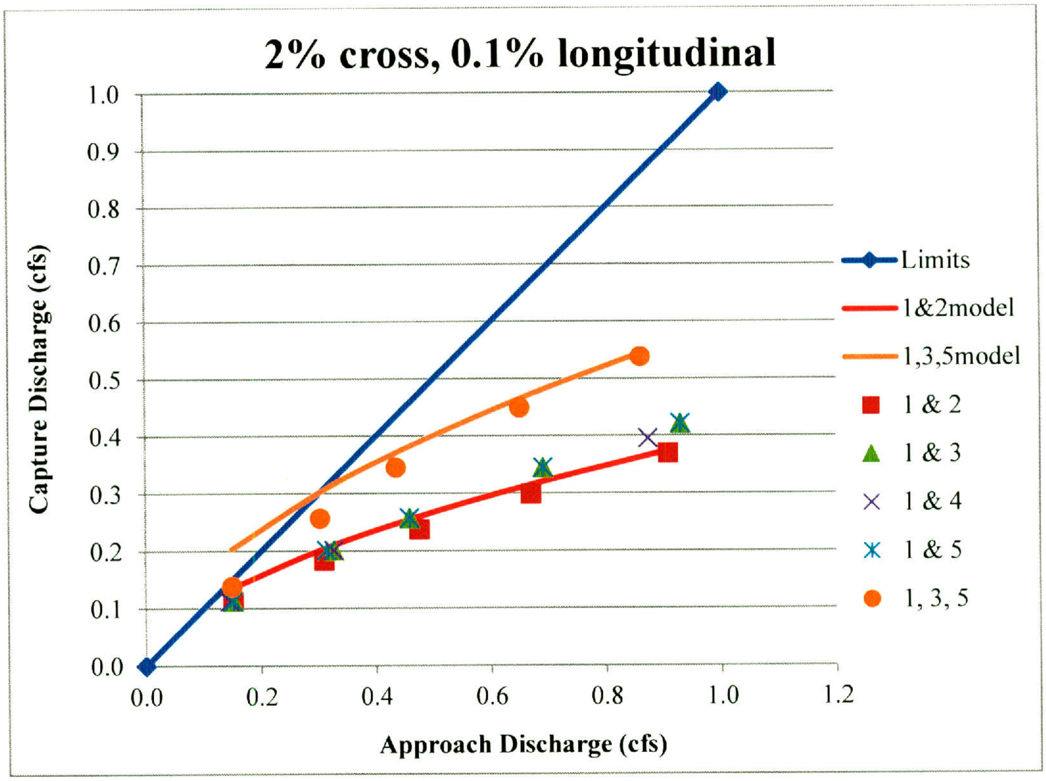


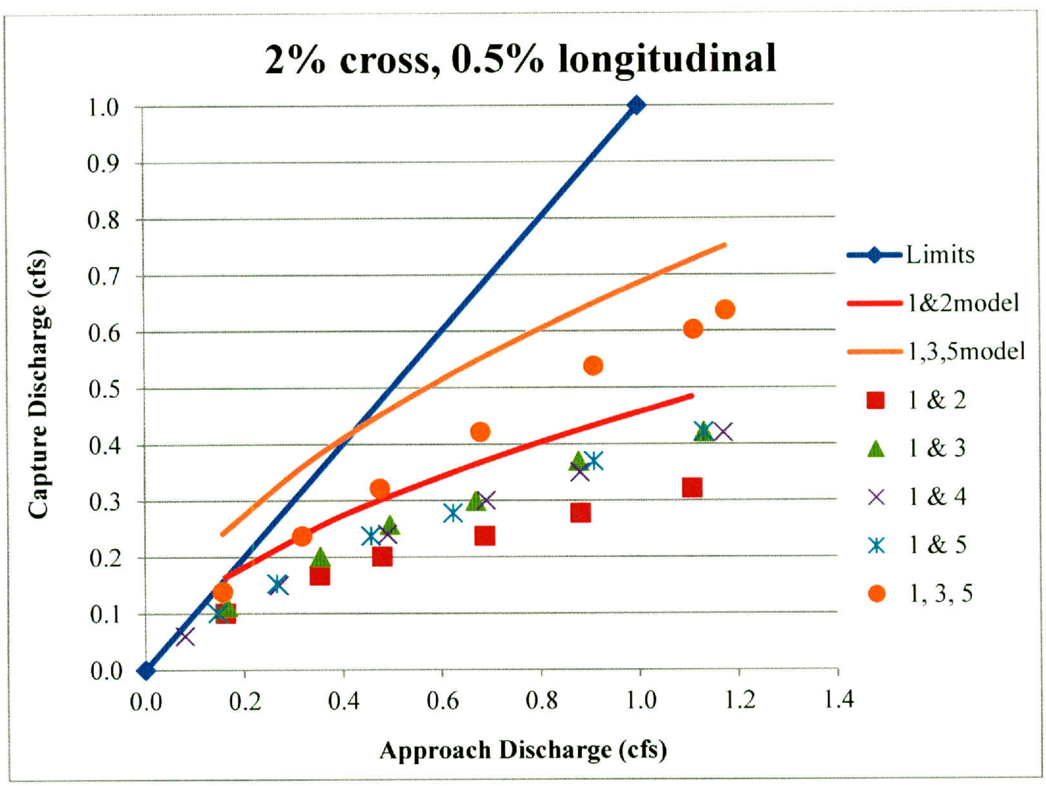
Figure C-25 Value of Residuals

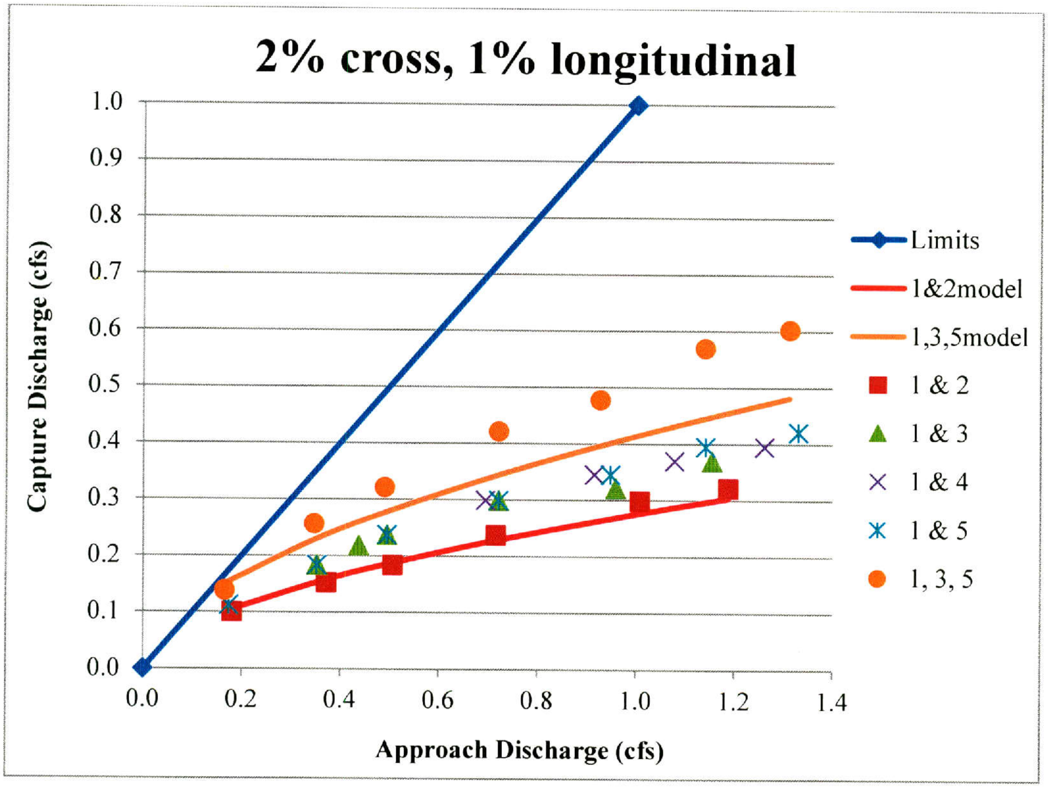
Conclusions

Considering each of these criteria, the effect of spacing on the hydraulic performance of rectangular drains is minimal. Although a slightly higher fraction of flow is captured by spacing the drains more than 1.5 ft apart, each drain captures essentially the same amount of flow. The magnitude of RMSE, gamma values, magnitude of error, and residuals indicates a sufficiently small difference exists between the measured captured flow values and the modeled values. Therefore, Equation 4.4 provides a sufficiently good fit for modeling purposes; the best method for increasing the amount of flow captured is to increase the number of drains.

Other Data Plots



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Approach Discharge (cfs)
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0.6
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0.4
0.3
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0.1
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0.2
0.4
0.6
0.8
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1.2
1.4
Limits
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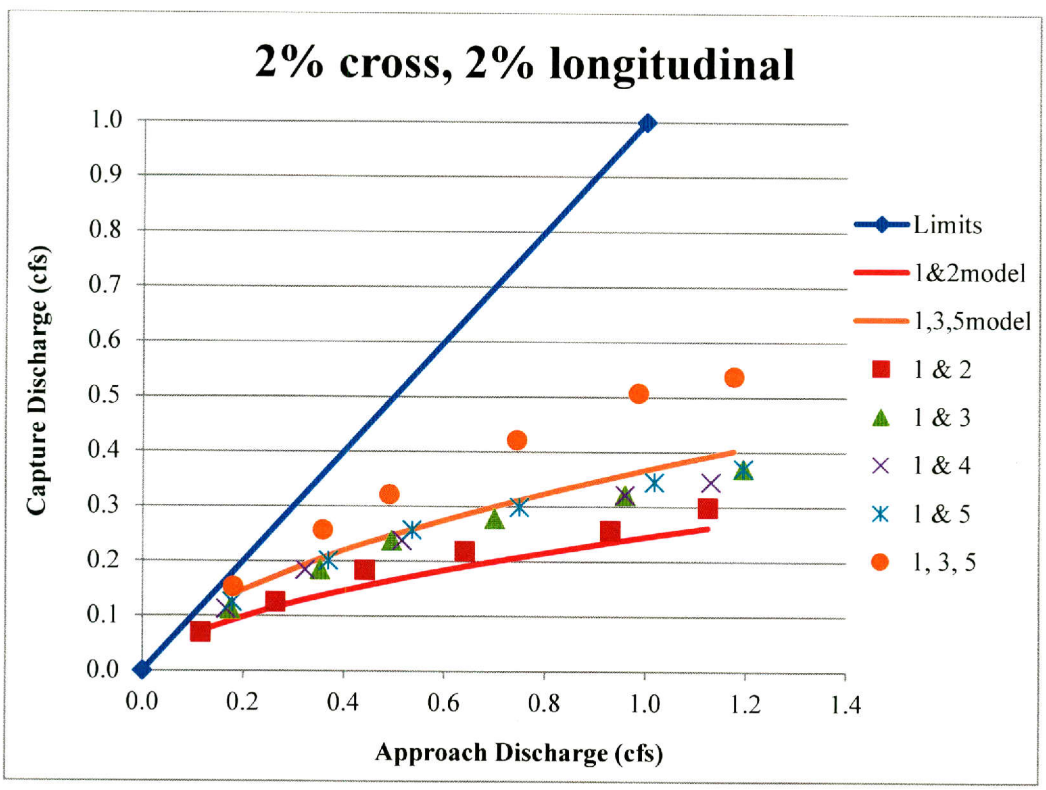
1 & 2
1 & 3
1 & 4
1 & 5
1, 3, 5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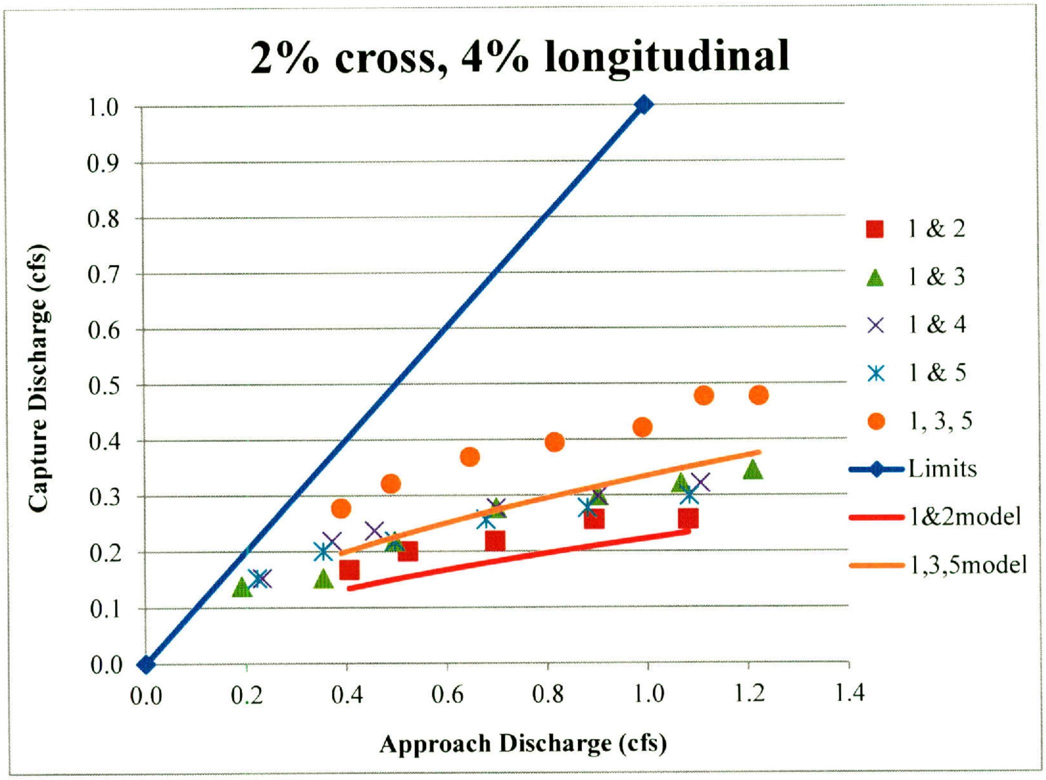
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1.0
1.2
1.4
Approach Discharge (cfs)
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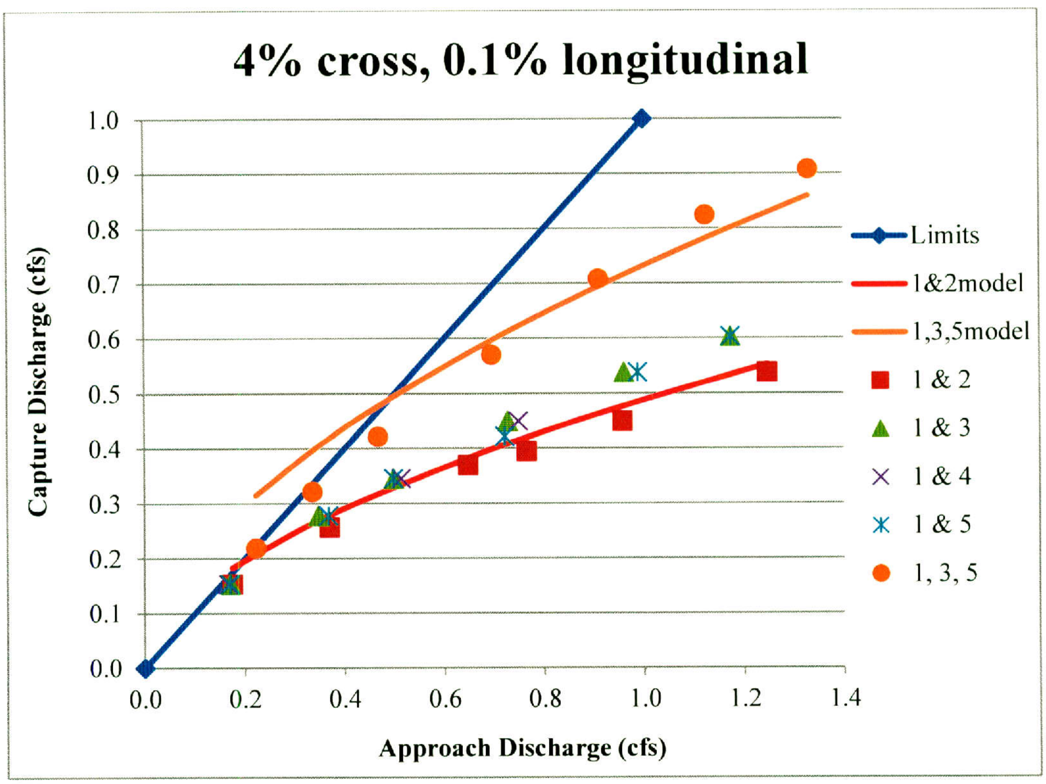
1 & 3
1 & 4
1 & 5
1, 3, 5
Limits
1&2model
1,3,5model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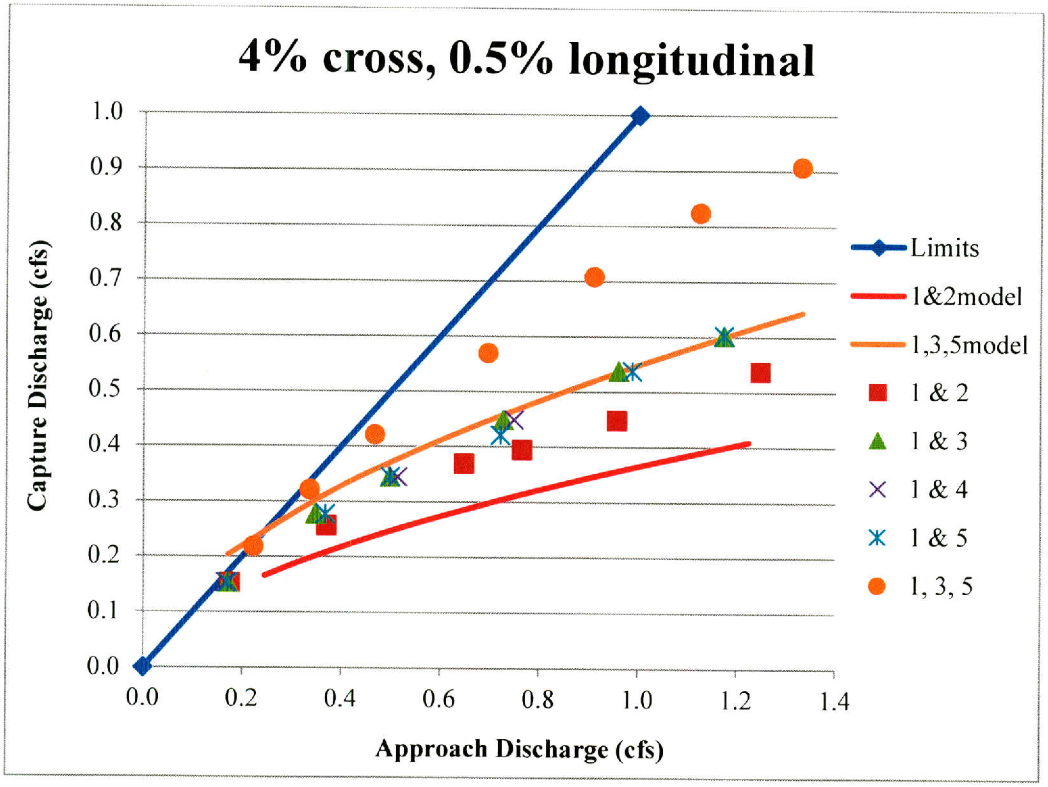
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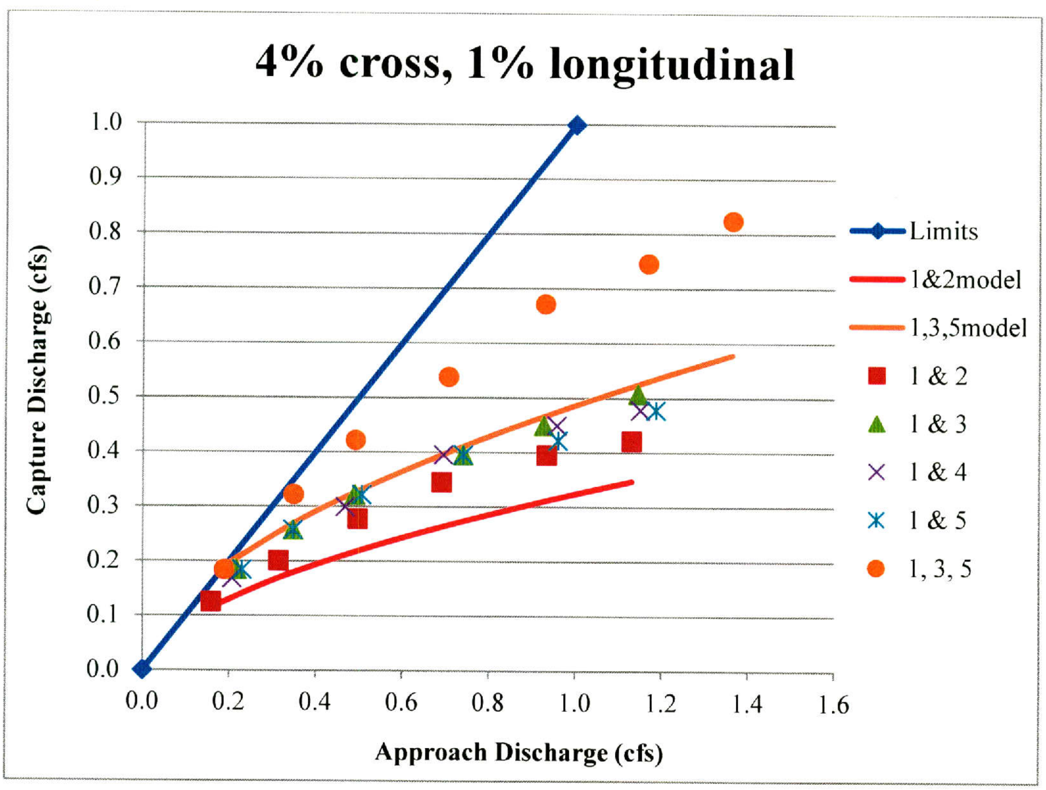
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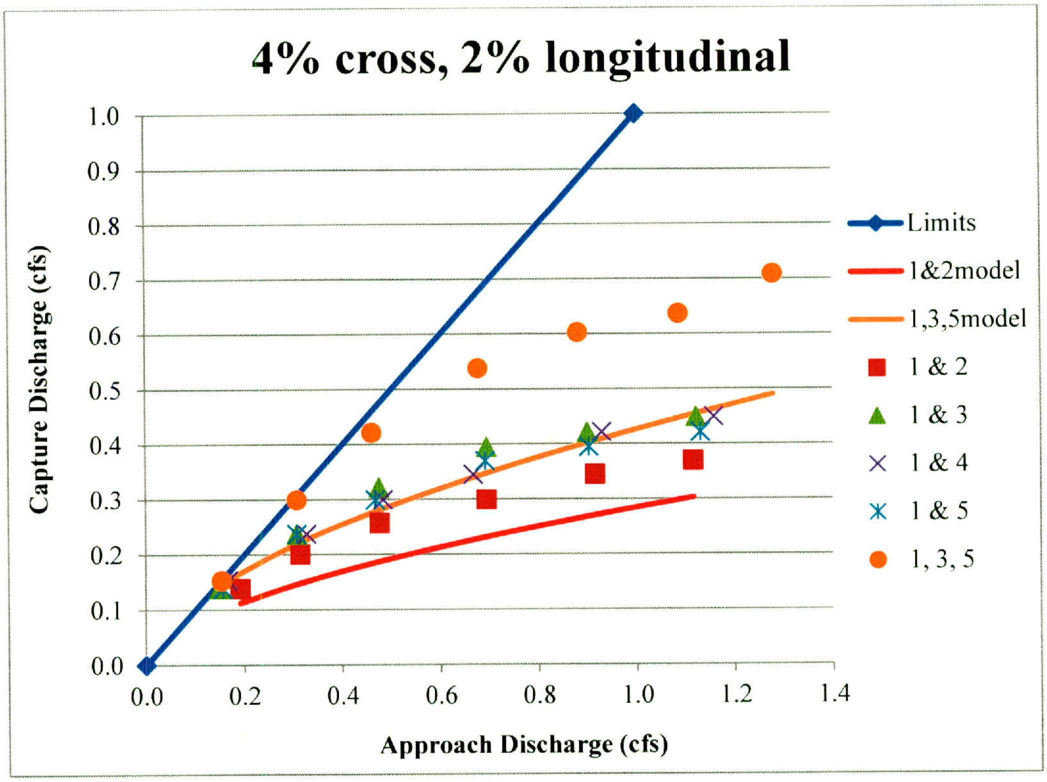
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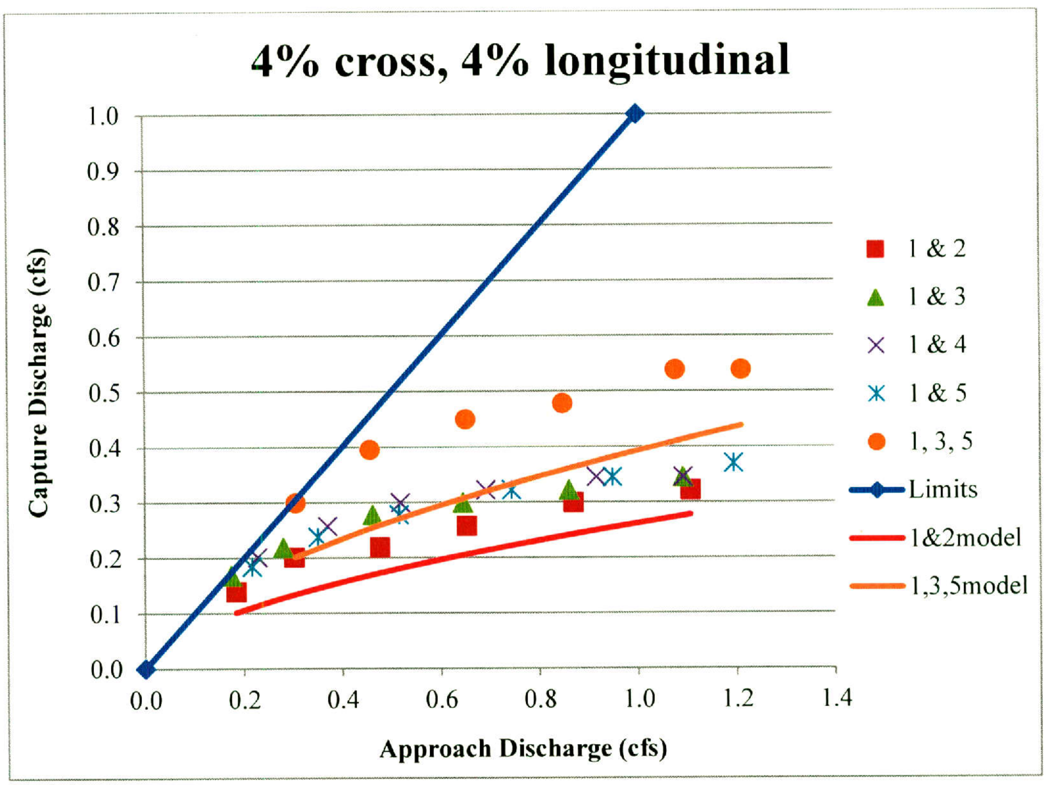
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Limits
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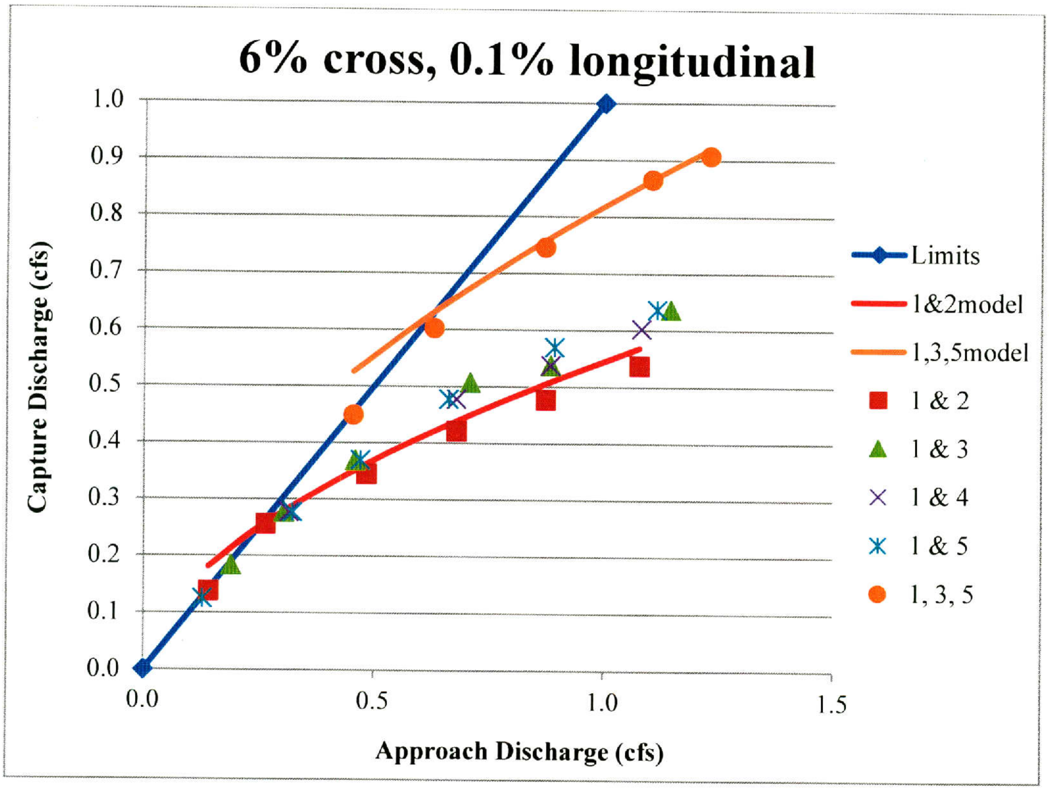
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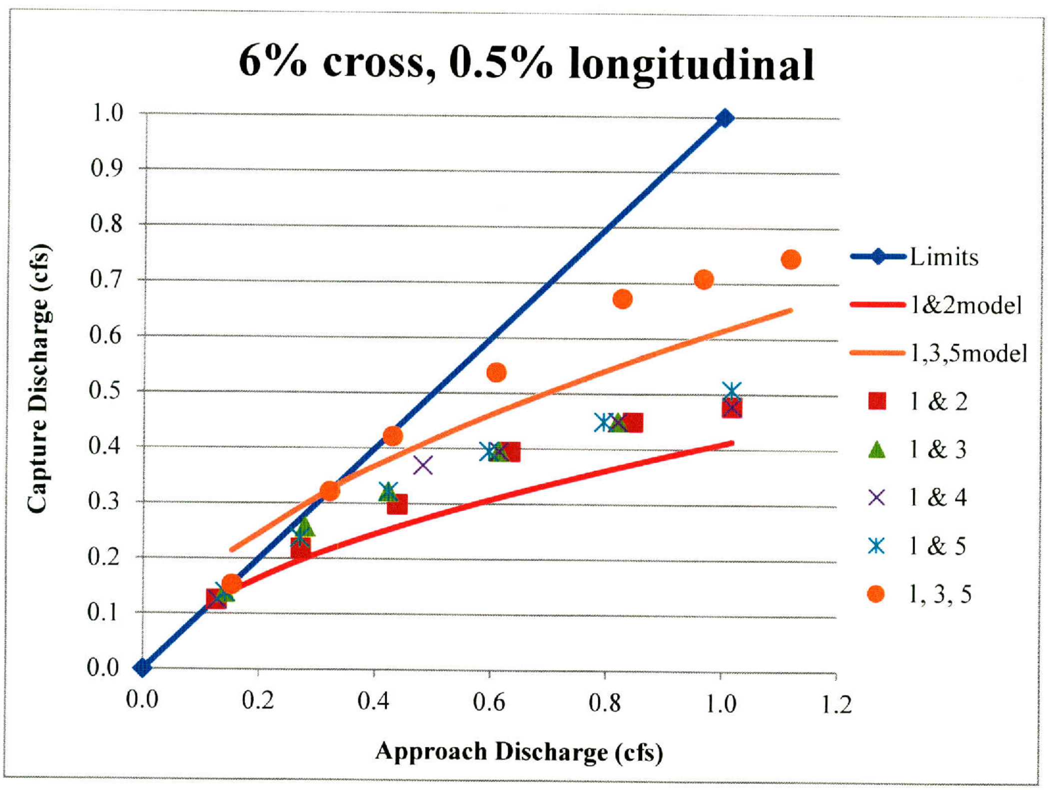
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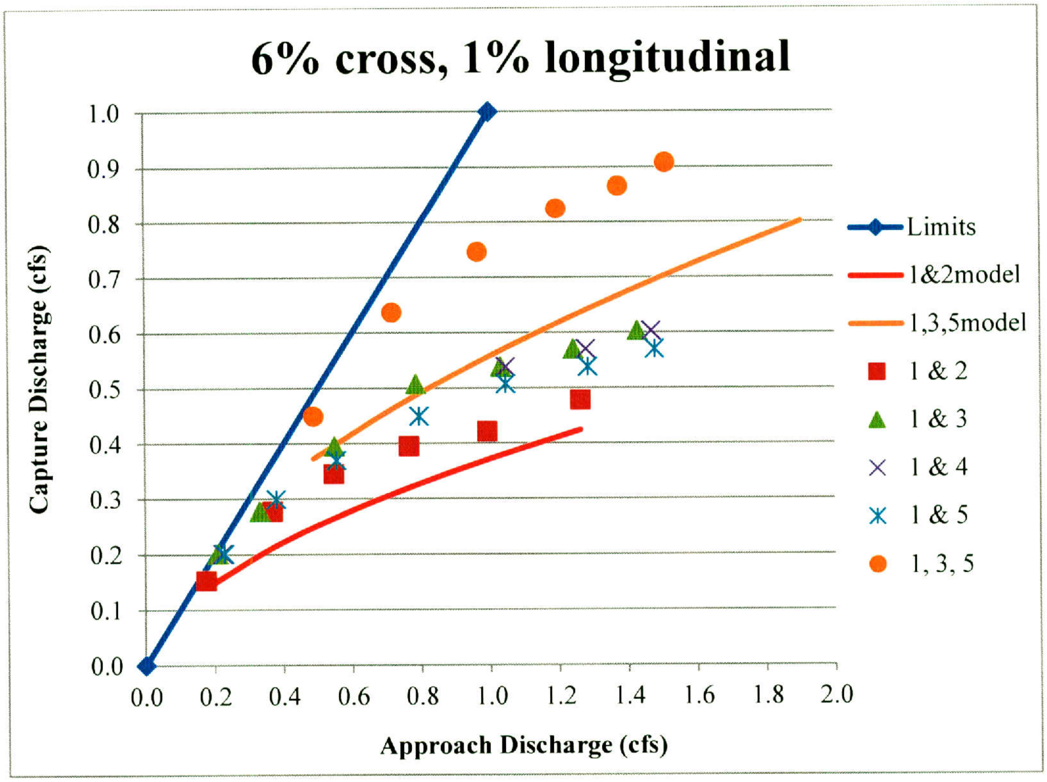
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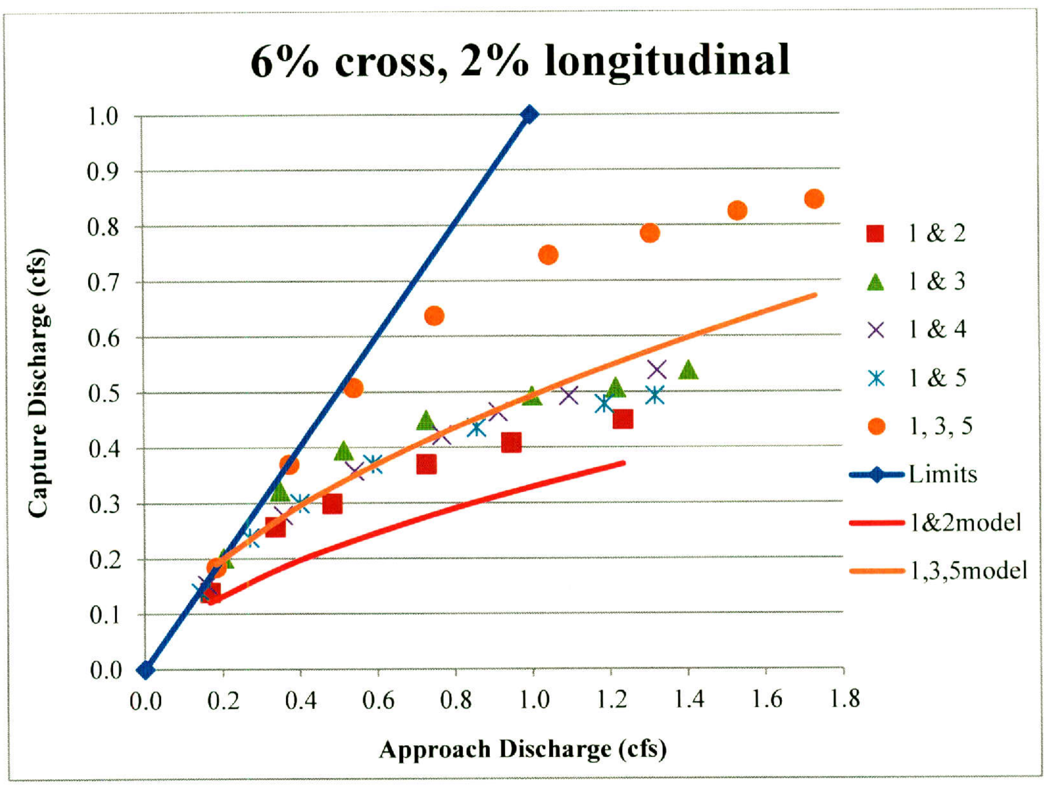
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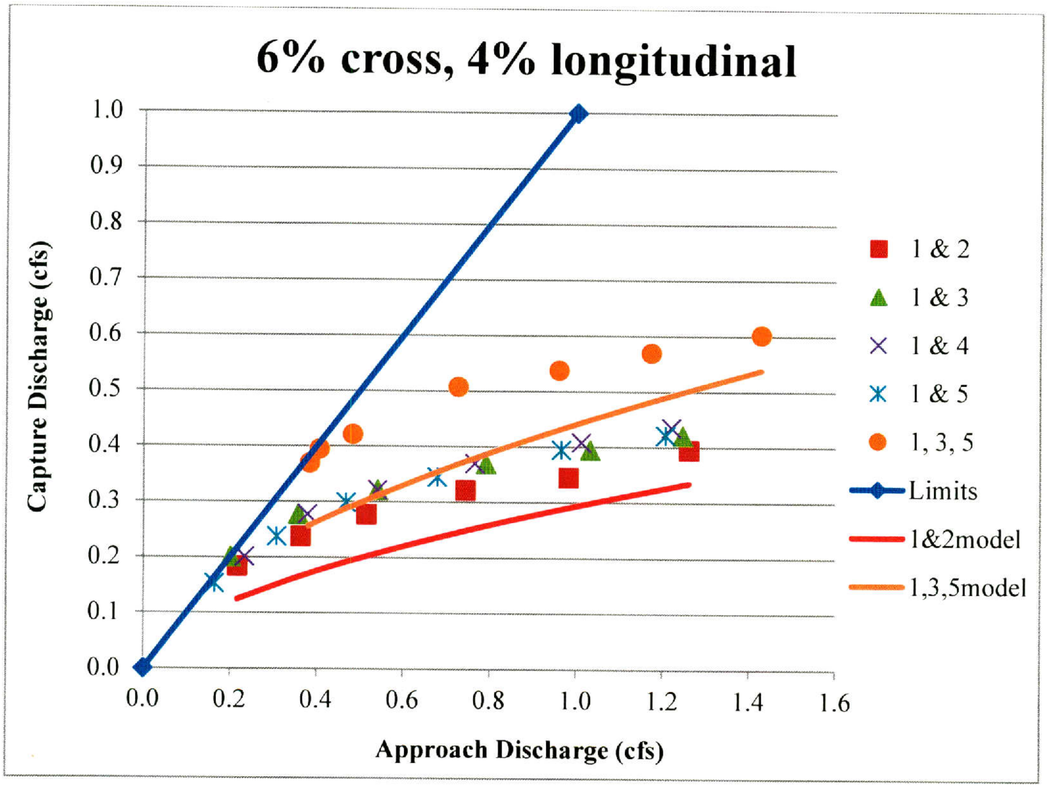
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