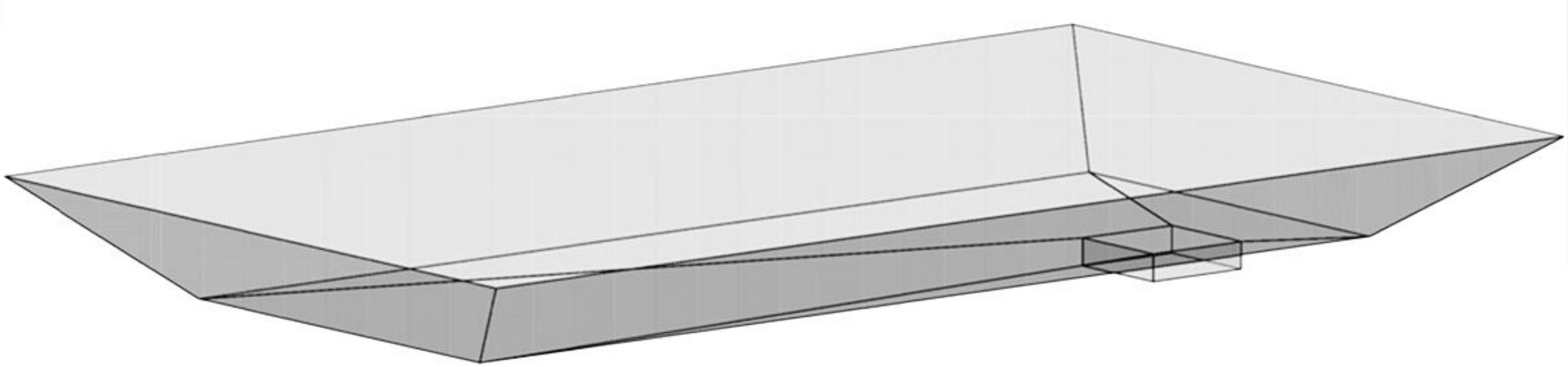

CASFM Lunch & Learn April 16, 2014

UD-FSD

a new tool to size and design full spectrum detention basins

presented by Ken MacKenzie & Myles Gardner
Urban Drainage and Flood Control District

Acknowledgements:

Programmers

Myles Garner, EI, UDFCD

Derek Rapp, PE, CFM, Peak Stormwater LLC

Jason Stawski, EI, UDFCD

Ryan Taylor, EI, UDFCD

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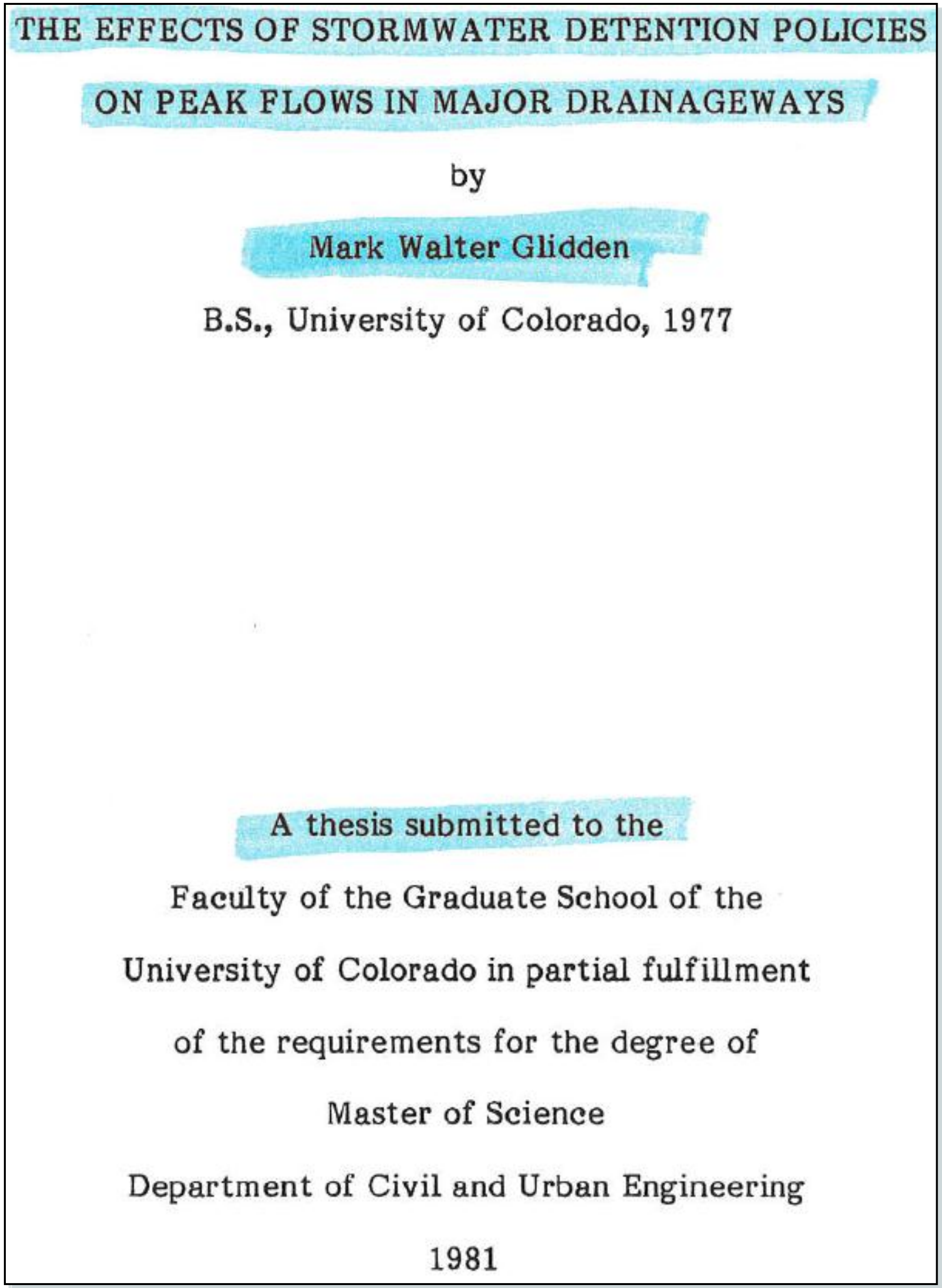
Tracy Bolger, PE, Muller Engineering Company

James Guo, PhD, PE, University of Colorado

Ben Urbonas, PE, Urban Watersheds Research Institute

Jim Wulliman, PE, Muller Engineering Company



THE EFFECTS OF STORMWATER DETENTION POLICIES ON PEAK FLOWS IN MAJOR DRAINAGEWAYS

by

Mark Walter Glidden

B.S., University of Colorado, 1977

A thesis submitted to the

Faculty of the Graduate School of the

University of Colorado in partial fulfillment

of the requirements for the degree of

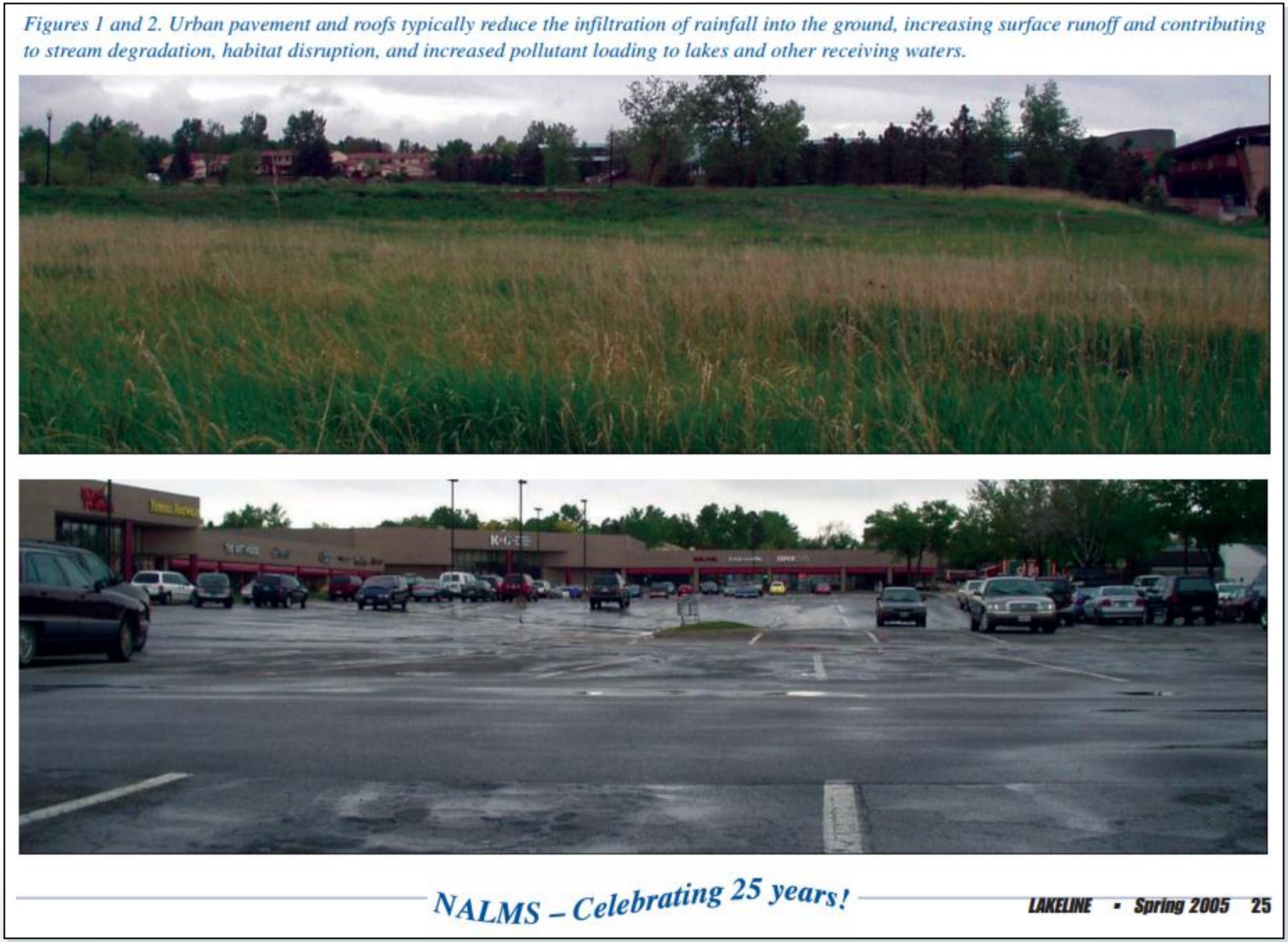
Master of Science

Department of Civil and Urban Engineering

1981

Learning from Nature:
Reducing Urban Stormwater Impacts

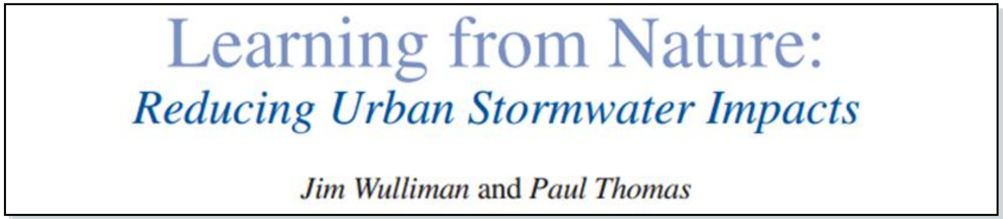
Jim Wulliman and *Paul Thomas*



Figures 1 and 2. Urban pavement and roofs typically reduce the infiltration of rainfall into the ground, increasing surface runoff and contributing to stream degradation, habitat disruption, and increased pollutant loading to lakes and other receiving waters.

NALMS – Celebrating 25 years!

LAKELINE ▪ Spring 2005 25



Learning from Nature:

Reducing Urban Stormwater Impacts

Jim Wulliman and *Paul Thomas*

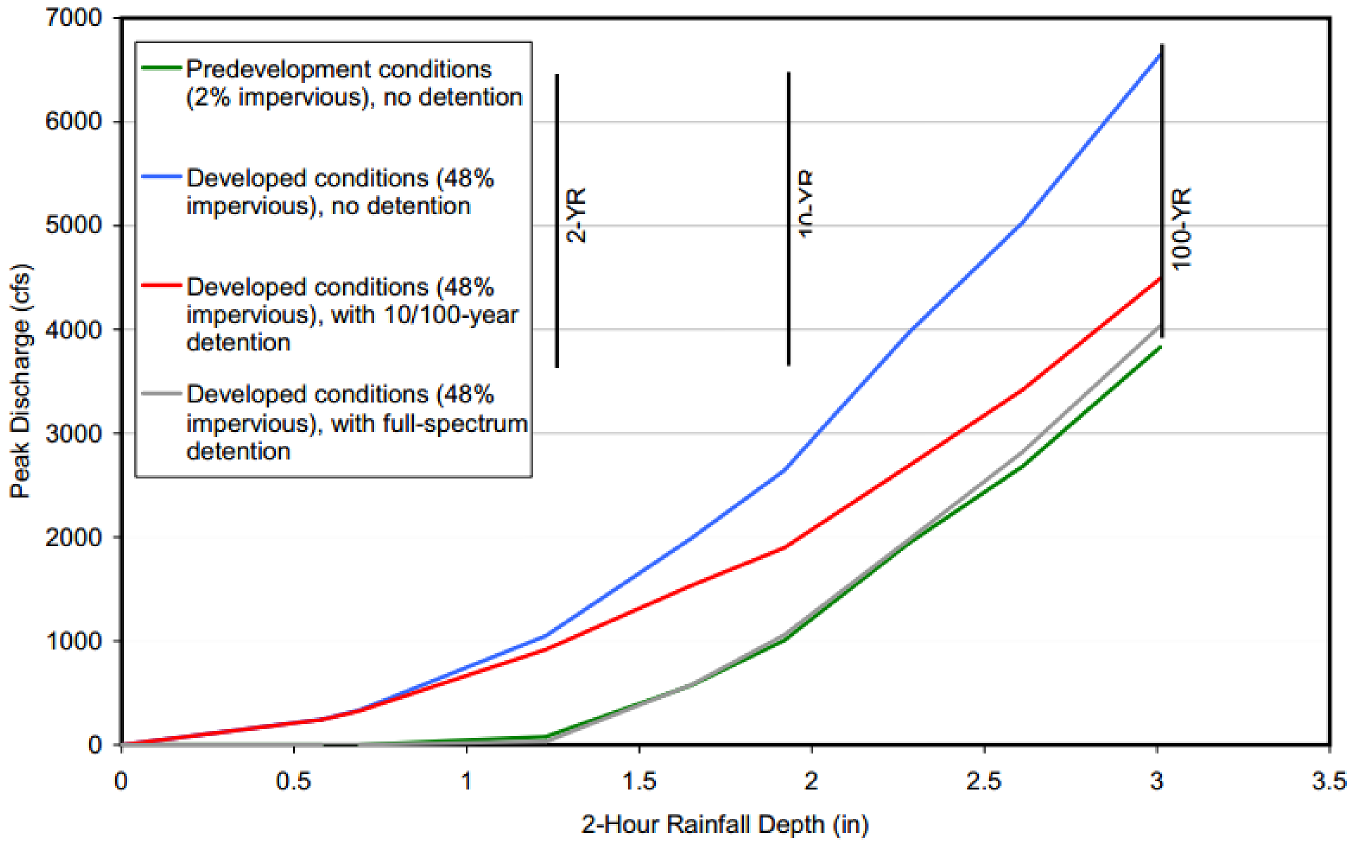
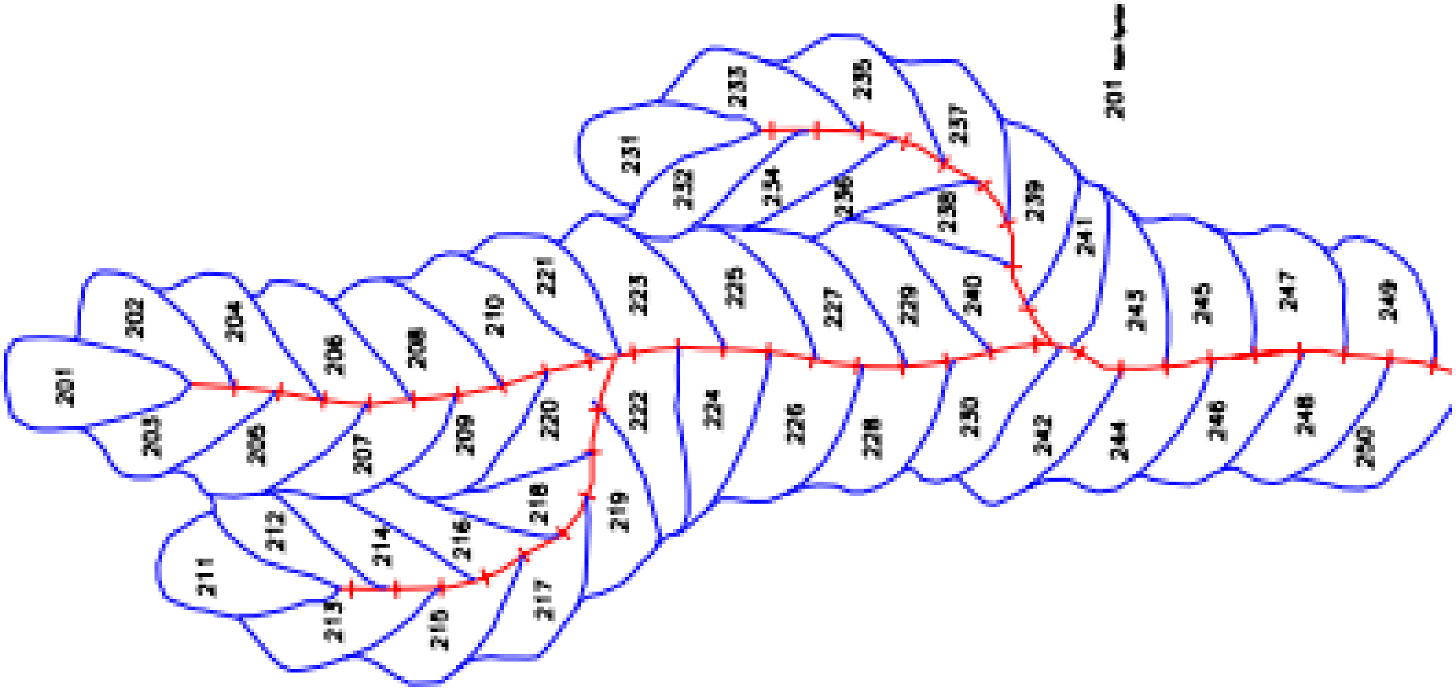


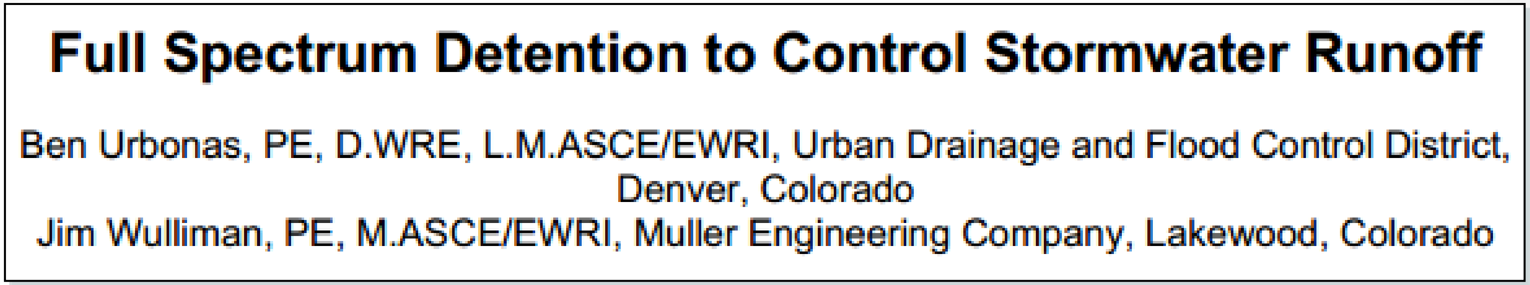
Figure 7. The full-spectrum *detention concept provides closer matching of natural, pre-development flow rates than conventional detention designs, especially for frequent, smaller storm events. It is expected that this detention concept could help reduce stream degradation and pollutant loading in urbanizing watersheds.*

Full Spectrum Detention to Control Stormwater Runoff

Ben Urbonas, PE, D.WRE, L.M.ASCE/EWRI, Urban Drainage and Flood Control District, Denver, Colorado
Jim Wulliman, PE, M.ASCE/EWRI, Muller Engineering Company, Lakewood, Colorado



EWRI 2007 World Water Congress, keynote presentation session of the 4th Urban Watershed Management Symposium



Full Spectrum Detention to Control Stormwater Runoff

Ben Urbonas, PE, D.WRE, L.M.ASCE/EWRI, Urban Drainage and Flood Control District,
Denver, Colorado
Jim Wulliman, PE, M.ASCE/EWRI, Muller Engineering Company, Lakewood, Colorado

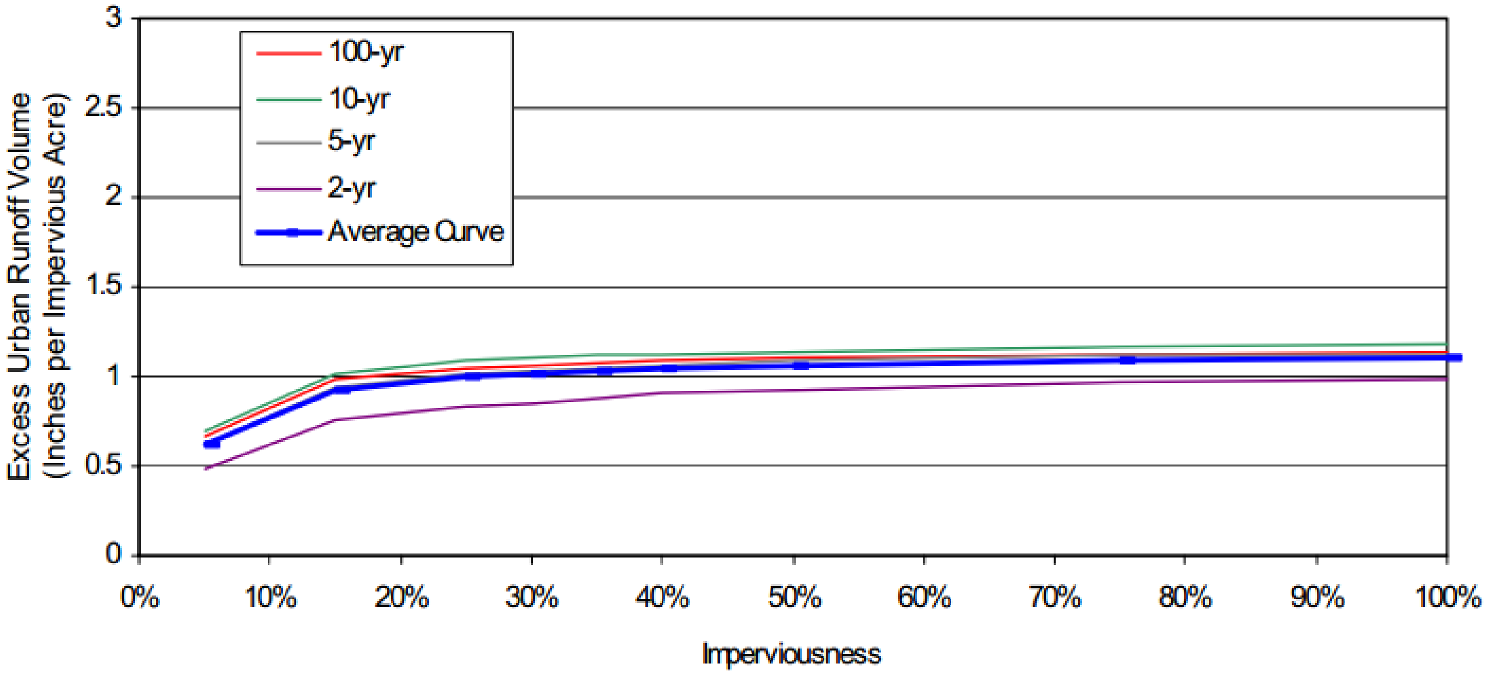


Figure 4. Excess Urban Runoff Volume for Hydrologic Soil Group C/D.

Full Spectrum Detention to Control Stormwater Runoff

Ben Urbonas, PE, D.WRE, L.M.ASCE/EWRI, Urban Drainage and Flood Control District, Denver, Colorado
Jim Wulliman, PE, M.ASCE/EWRI, Muller Engineering Company, Lakewood, Colorado

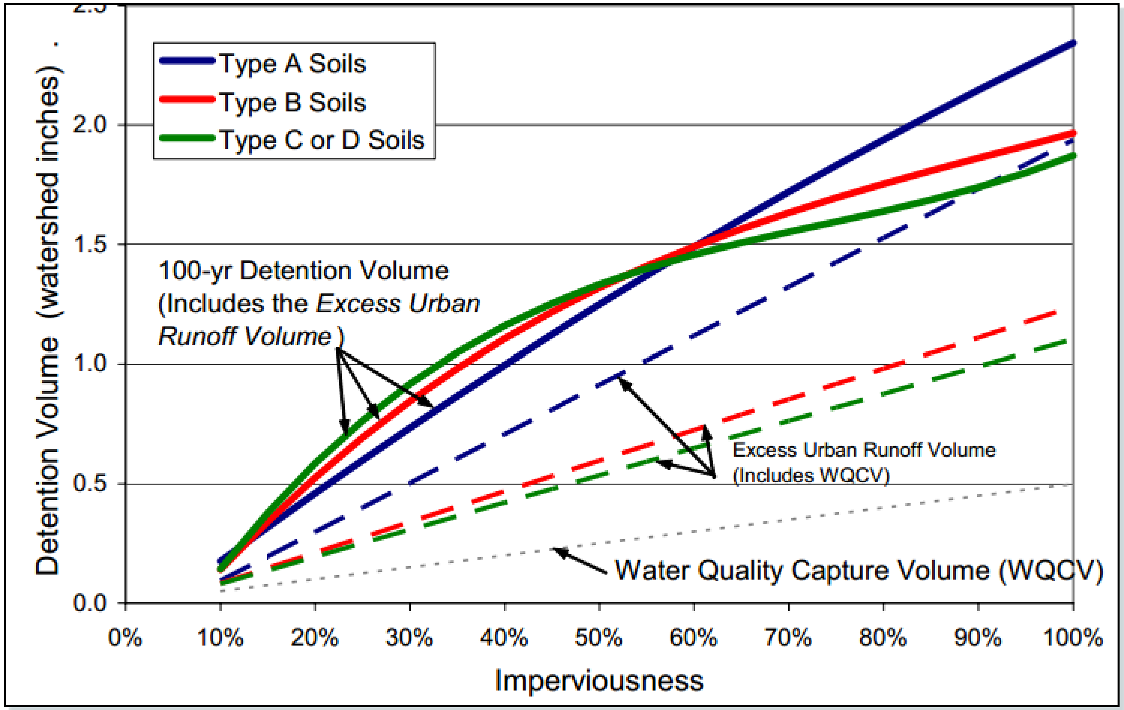
NRCS Soil Group A: $EURV_A = 1.1 \cdot (2.0491 \cdot i - 0.1113)$

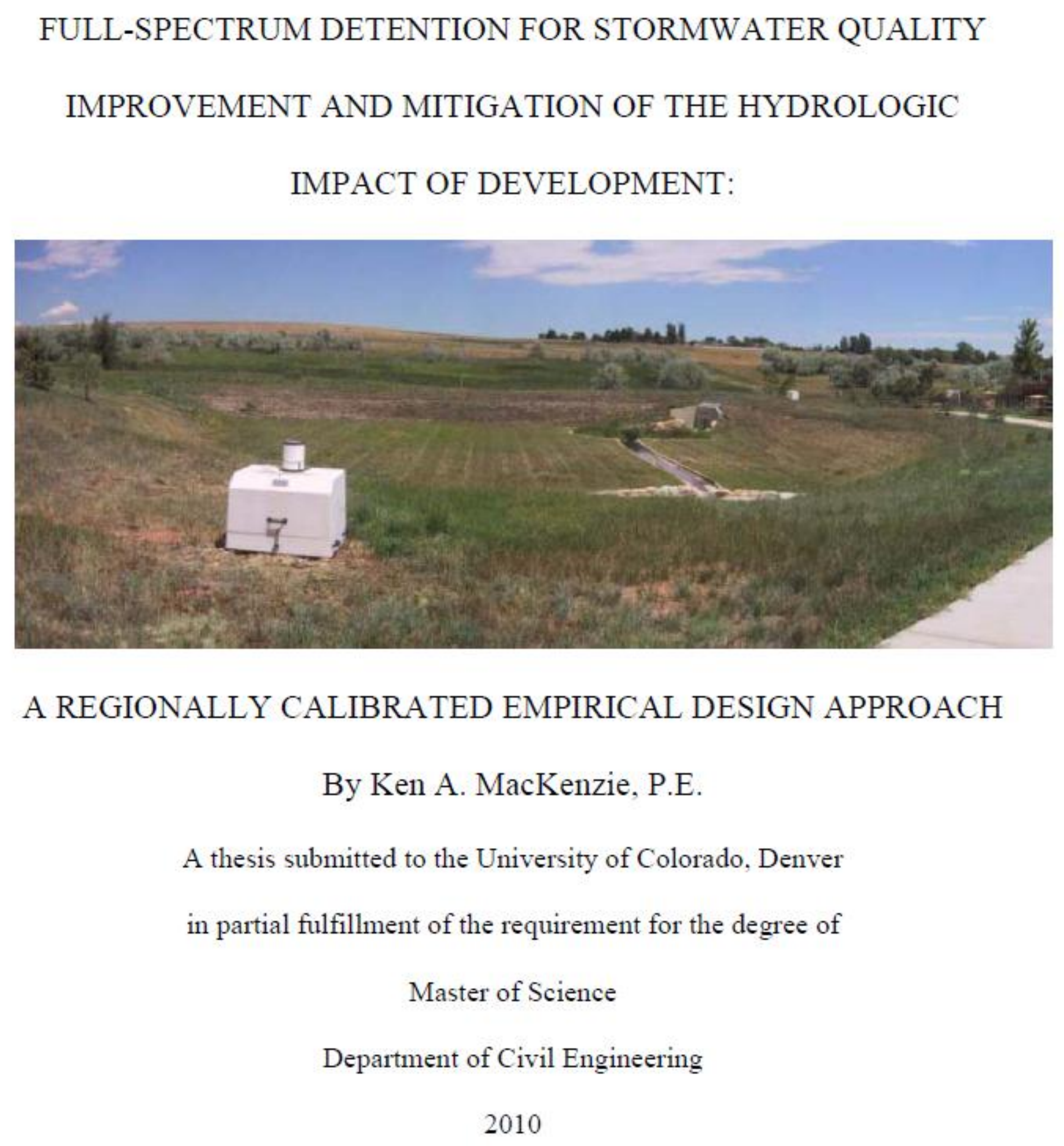
NRCS Soil Group B: $EURV_B = 1.1 \cdot (1.2846 \cdot i - 0.0461)$

NRCS Soil Group C/D: $EURV_{CD} = 1.1 \cdot (1.1381 \cdot i - 0.0339)$

in which, $EURV_K$ = Excess Urban Runoff Volume in watershed inches ($K = A, B$ *or* CD)

i = Imperviousness ratio (I/100)





FULL-SPECTRUM DETENTION FOR STORMWATER QUALITY IMPROVEMENT AND MITIGATION OF THE HYDROLOGIC IMPACT OF DEVELOPMENT:

A REGIONALLY CALIBRATED EMPIRICAL DESIGN APPROACH

By Ken A. MacKenzie, P.E.

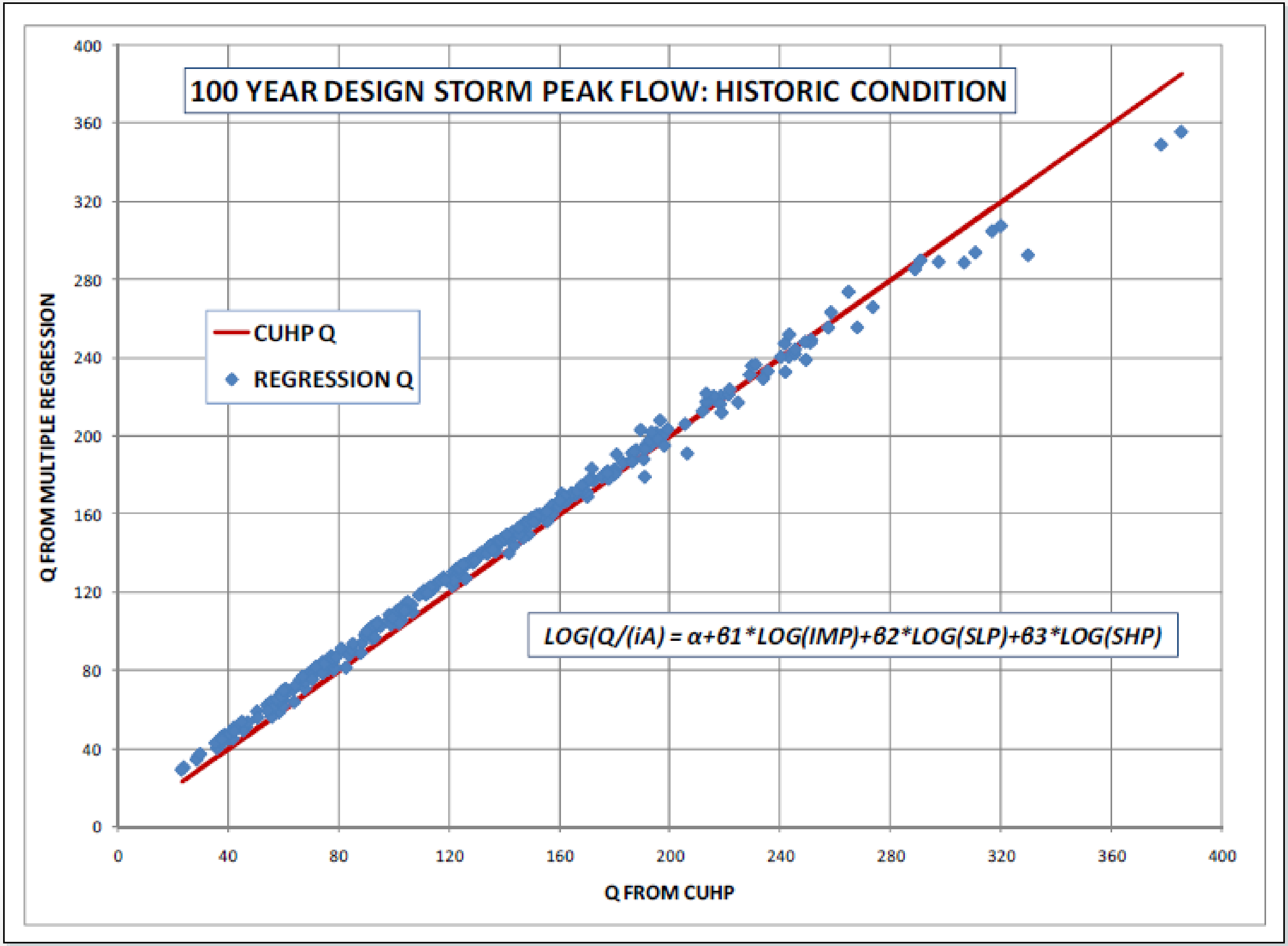
A thesis submitted to the University of Colorado, Denver

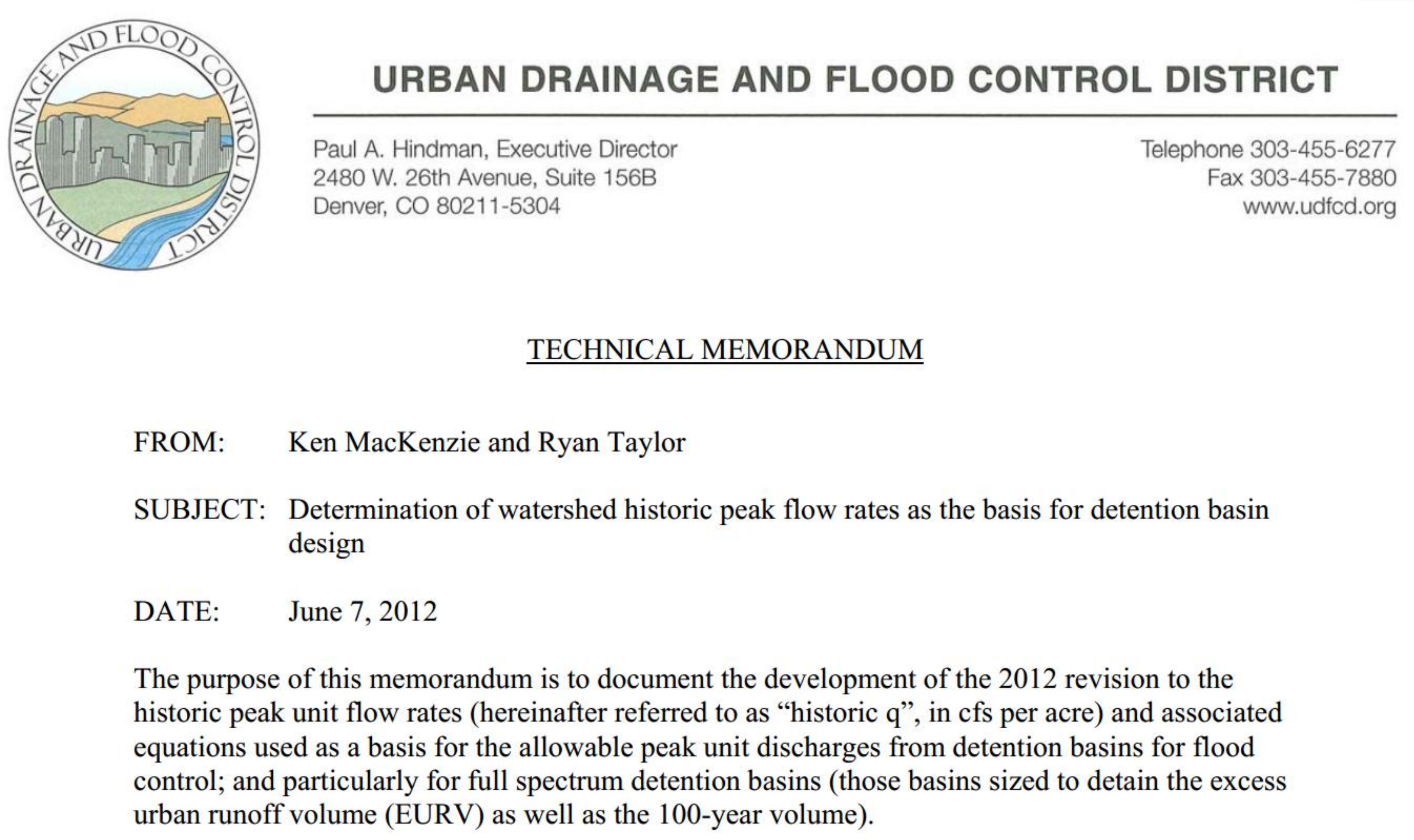
in partial fulfillment of the requirement for the degree of

Master of Science

Department of Civil Engineering

2010


100 YEAR DESIGN STORM PEAK FLOW: HISTORIC CONDITION
CUHP Q
REGRESSION Q
LOG(Q/(iA) = α+β1*LOG(IMP)+β2*LOG(SLP)+β3*LOG(SHP)
Q FROM MULTIPLE REGRESSION
Q FROM CUHP
0
40
80
120
160
200
240
280
320
360
400



URBAN DRAINAGE AND FLOOD CONTROL DISTRICT

Paul A. Hindman, Executive Director
2480 W. 26th Avenue, Suite 156B
Denver, CO 80211-5304

Telephone 303-455-6277
Fax 303-455-7880
www.udfcd.org

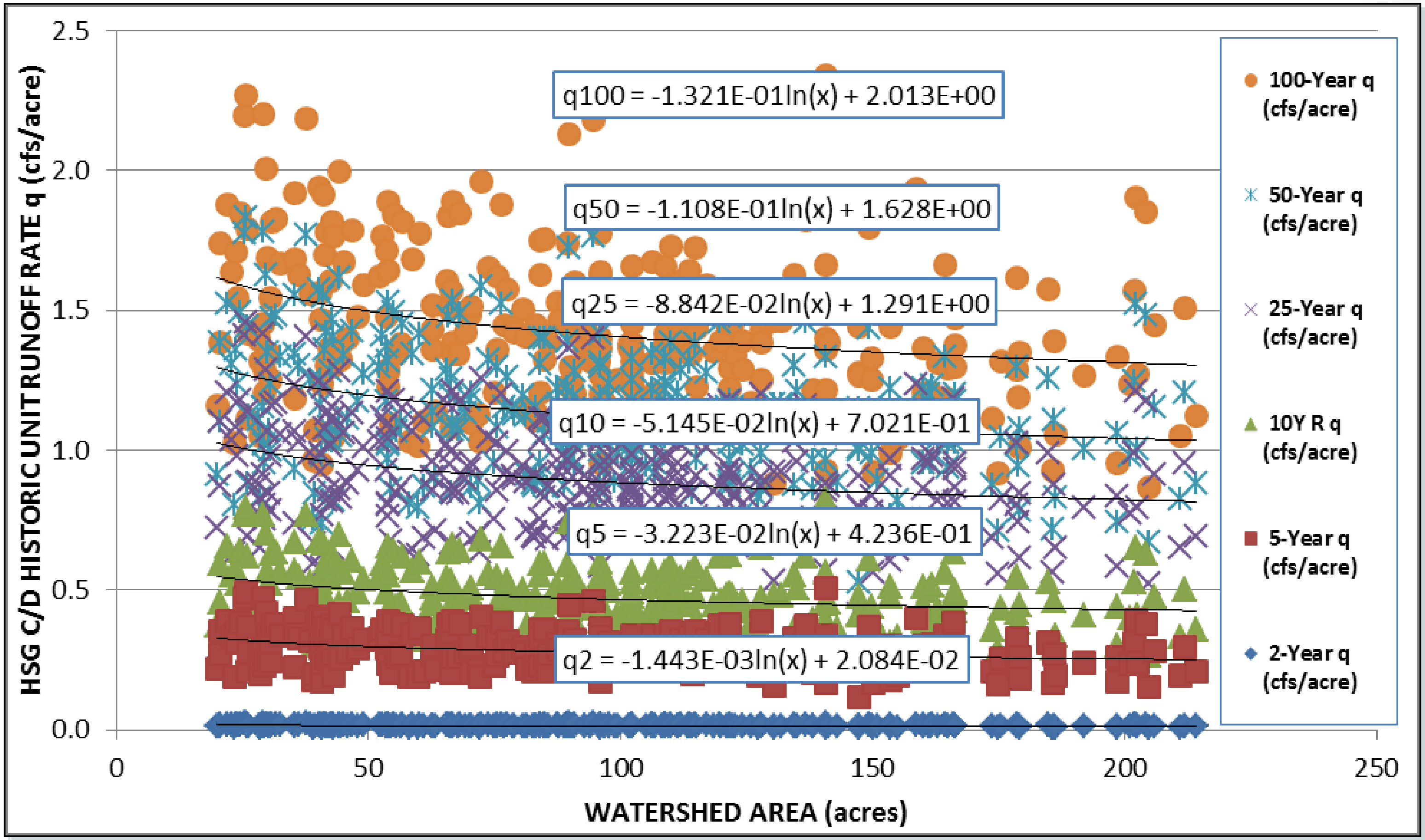
TECHNICAL MEMORANDUM

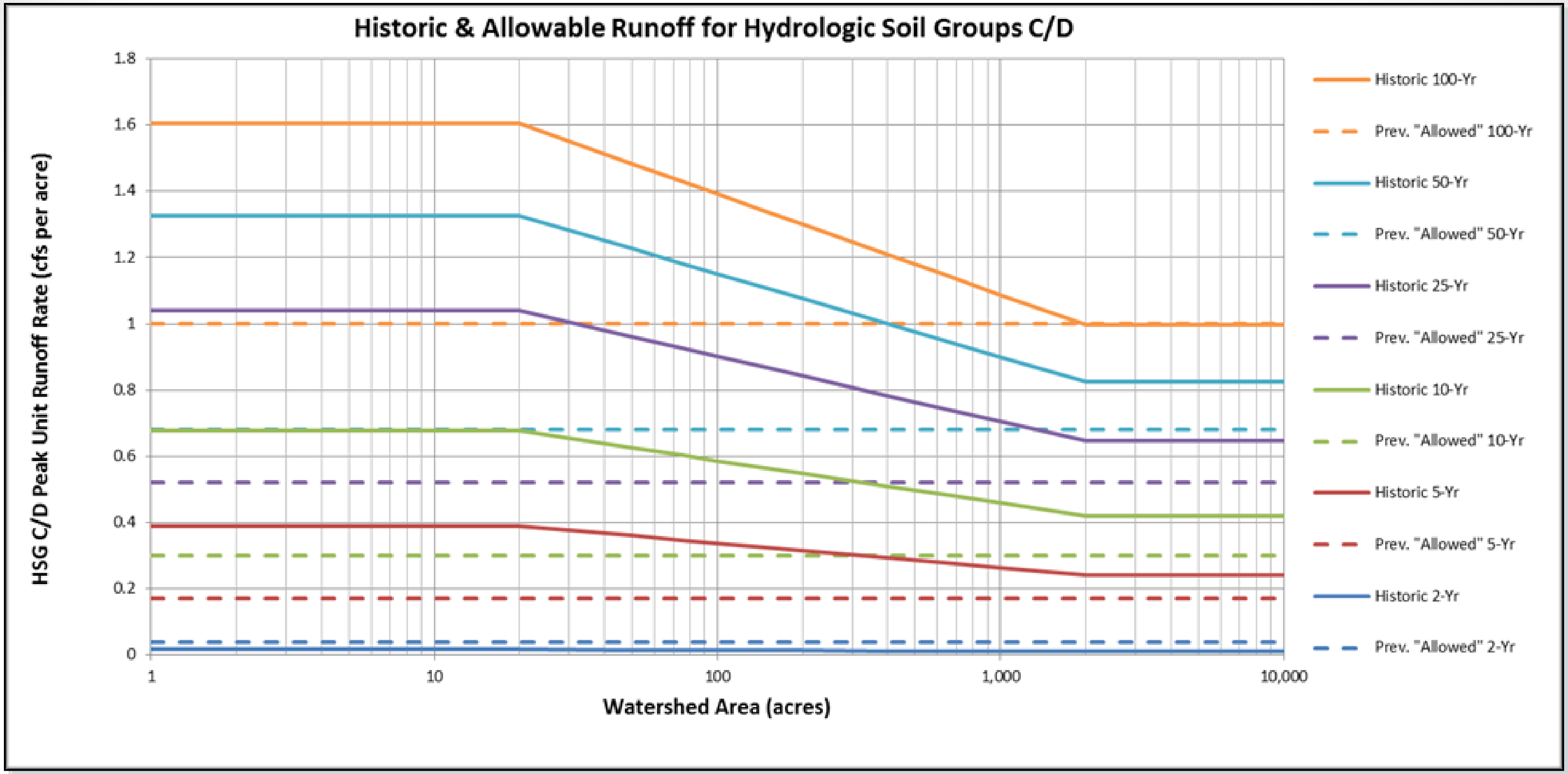
FROM: Ken MacKenzie and Ryan Taylor

SUBJECT: Determination of watershed historic peak flow rates as the basis for detention basin design

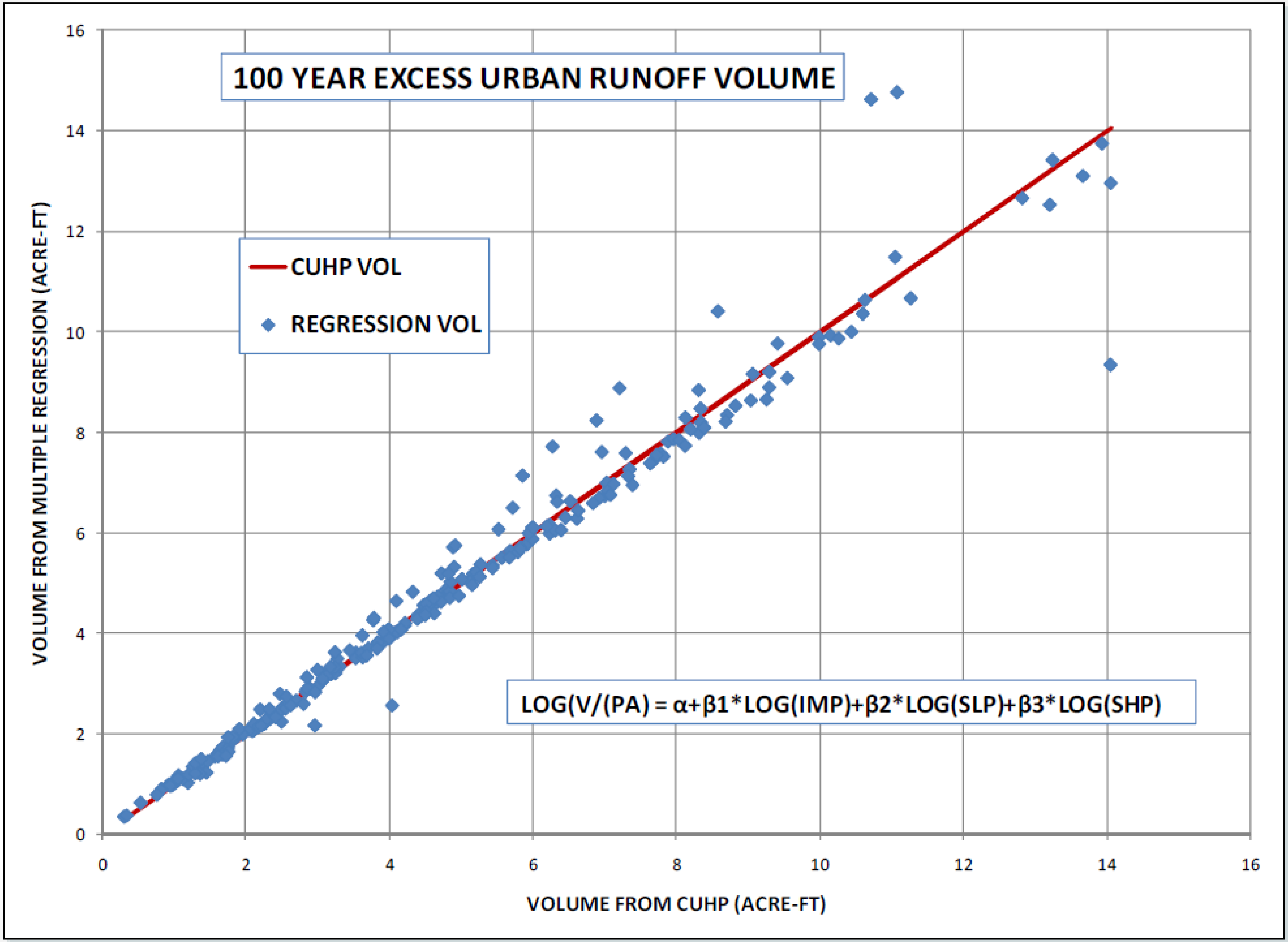
DATE: June 7, 2012

The purpose of this memorandum is to document the development of the 2012 revision to the historic peak unit flow rates (hereinafter referred to as "historic q", in cfs per acre) and associated equations used as a basis for the allowable peak unit discharges from detention basins for flood control; and particularly for full spectrum detention basins (those basins sized to detain the excess urban runoff volume (EURV) as well as the 100-year volume).

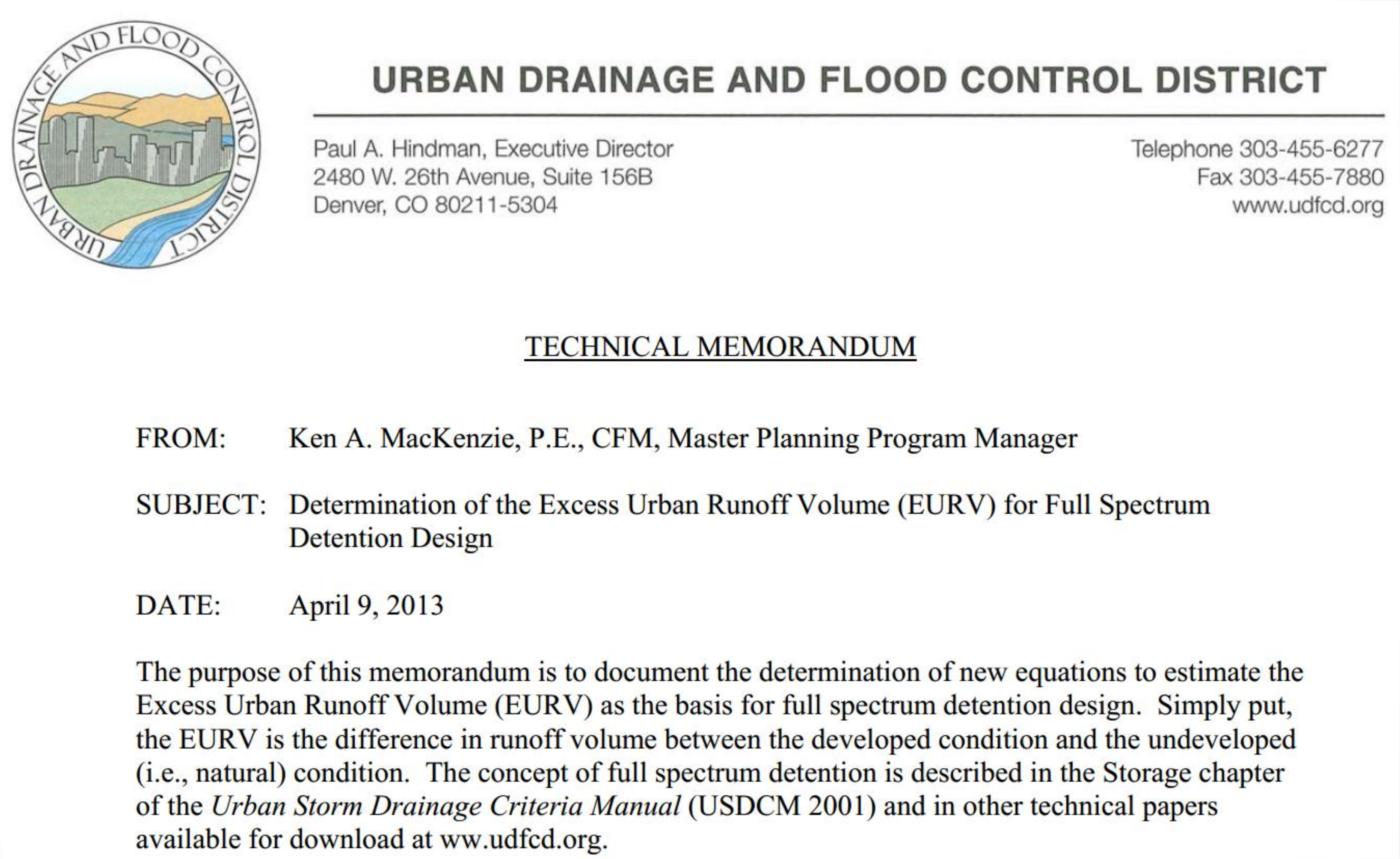
q100 = -1.321E-01ln(x) + 2.013E+00
q50 = -1.108E-01ln(x) + 1.628E+00
q25 = -8.842E-02ln(x) + 1.291E+00
q10 = -5.145E-02ln(x) + 7.021E-01
q5 = -3.223E-02ln(x) + 4.236E-01
q2 = -1.443E-03ln(x) + 2.084E-02
● 100-Year q (cfs/acre)
✳ 50-Year q (cfs/acre)
× 25-Year q (cfs/acre)
▲ 10Y R q (cfs/acre)
■ 5-Year q (cfs/acre)
◆ 2-Year q (cfs/acre)
HSG C/D HISTORIC UNIT RUNOFF RATE q (cfs/acre)
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
200
250
WATERSHED AREA (acres)


Historic & Allowable Runoff for Hydrologic Soil Groups C/D

Return Period	Hydrologic Soil Group A	Hydrologic Soil Group B	Hydrologic Soil Groups C and D
2-Year	$q_2 = 0$	$q_2 = -0.00128 * LN(A) + 0.017$	$q_2 = -0.00144 * LN(A) + 0.021$
5-Year	$q_5 = -0.00124 * LN(A) + 0.015$	$q_5 = -0.0221 * LN(A) + 0.27$	$q_5 = -0.032 * LN(A) + 0.42$
10-Year	$q_{10} = -0.002 * LN(A) + 0.025$	$q_{10} = -0.04 * LN(A) + 0.52$	$q_{10} = -0.051 * LN(A) + 0.7$
25-Year	$q_{25} = -0.0236 * LN(A) + 0.29$	$q_{25} = -0.08 * LN(A) + 1.15$	$q_{25} = -0.088 * LN(A) + 1.29$
50-Year	$q_{50} = -0.047 * LN(A) + 0.59$	$q_{50} = -0.103 * LN(A) + 1.48$	$q_{50} = -0.11 * LN(A) + 1.63$
100-Year	$q_{100} = -0.073 * LN(A) + 0.95$	$q_{100} = -0.124 * LN(A) + 1.86$	$q_{100} = -0.132 * LN(A) + 2$



LOG(V/(PA) = α+β1*LOG(IMP)+β2*LOG(SLP)+β3*LOG(SHP)



URBAN DRAINAGE AND FLOOD CONTROL DISTRICT

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Telephone 303-455-6277
Fax 303-455-7880
www.udfcd.org

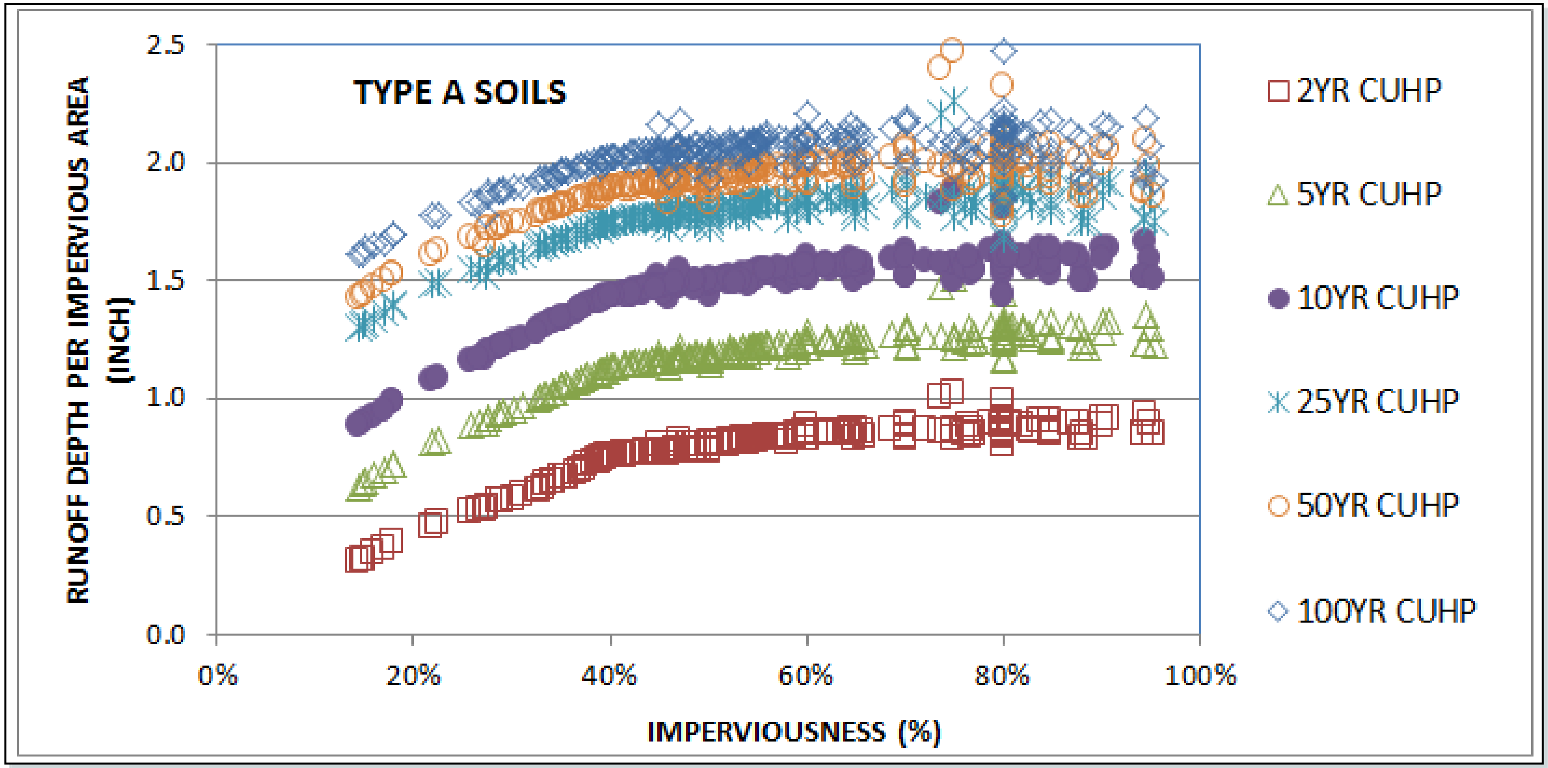
TECHNICAL MEMORANDUM

FROM: Ken A. MacKenzie, P.E., CFM, Master Planning Program Manager

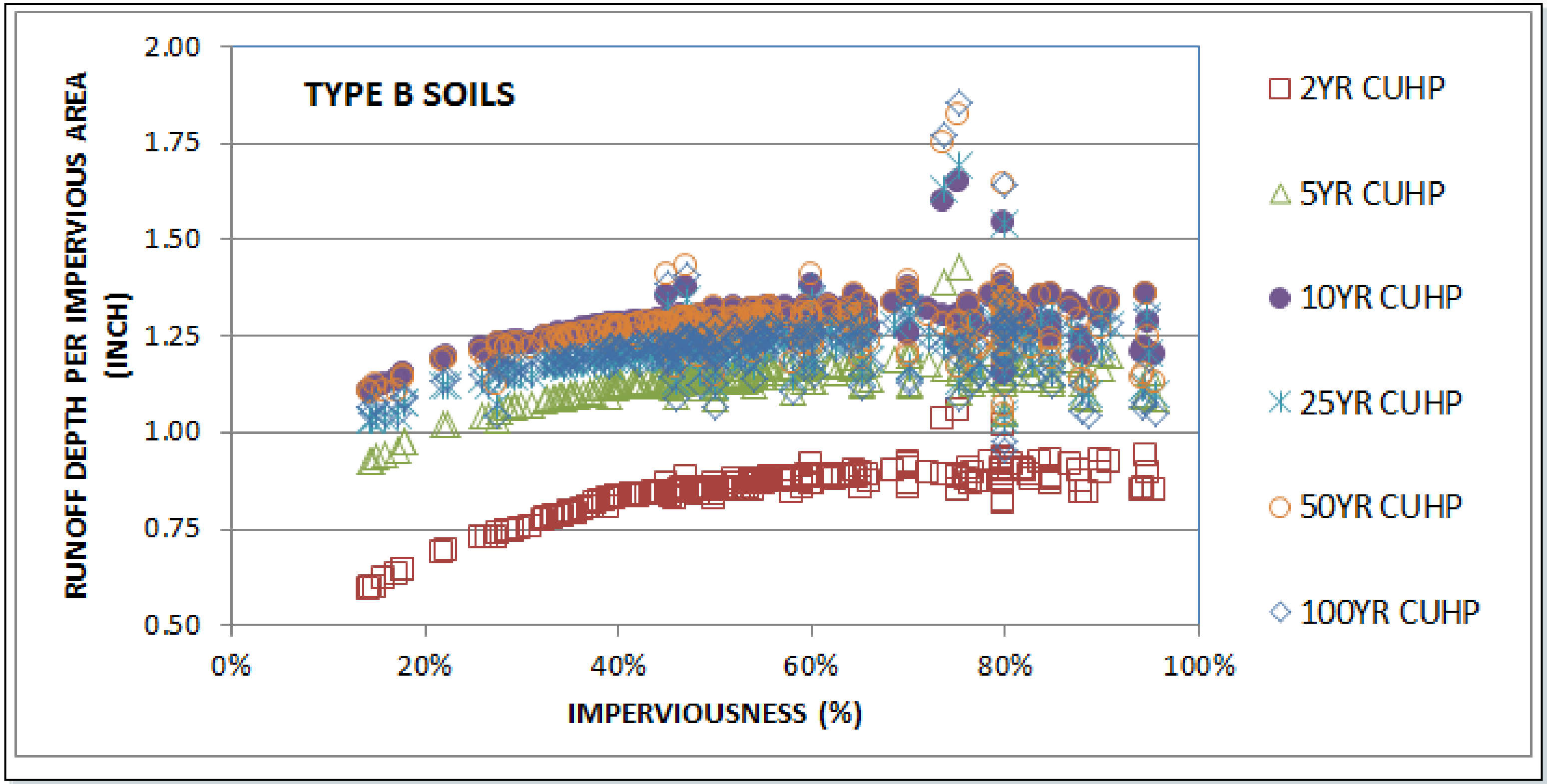
SUBJECT: Determination of the Excess Urban Runoff Volume (EURV) for Full Spectrum Detention Design

DATE: April 9, 2013

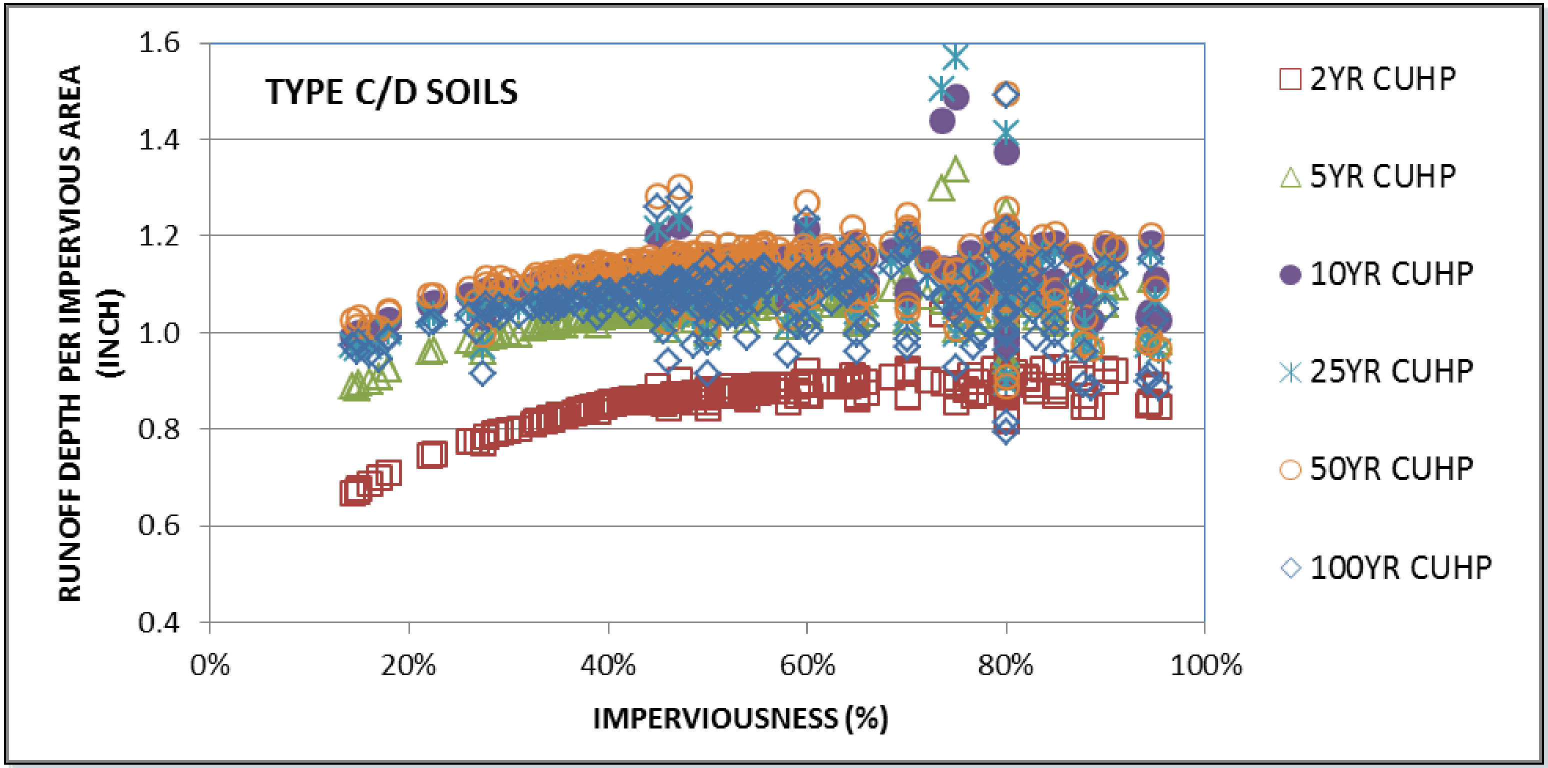
The purpose of this memorandum is to document the determination of new equations to estimate the Excess Urban Runoff Volume (EURV) as the basis for full spectrum detention design. Simply put, the EURV is the difference in runoff volume between the developed condition and the undeveloped (i.e., natural) condition. The concept of full spectrum detention is described in the Storage chapter of the *Urban Storm Drainage Criteria Manual* (USDCM 2001) and in other technical papers available for download at www.udfcd.org.



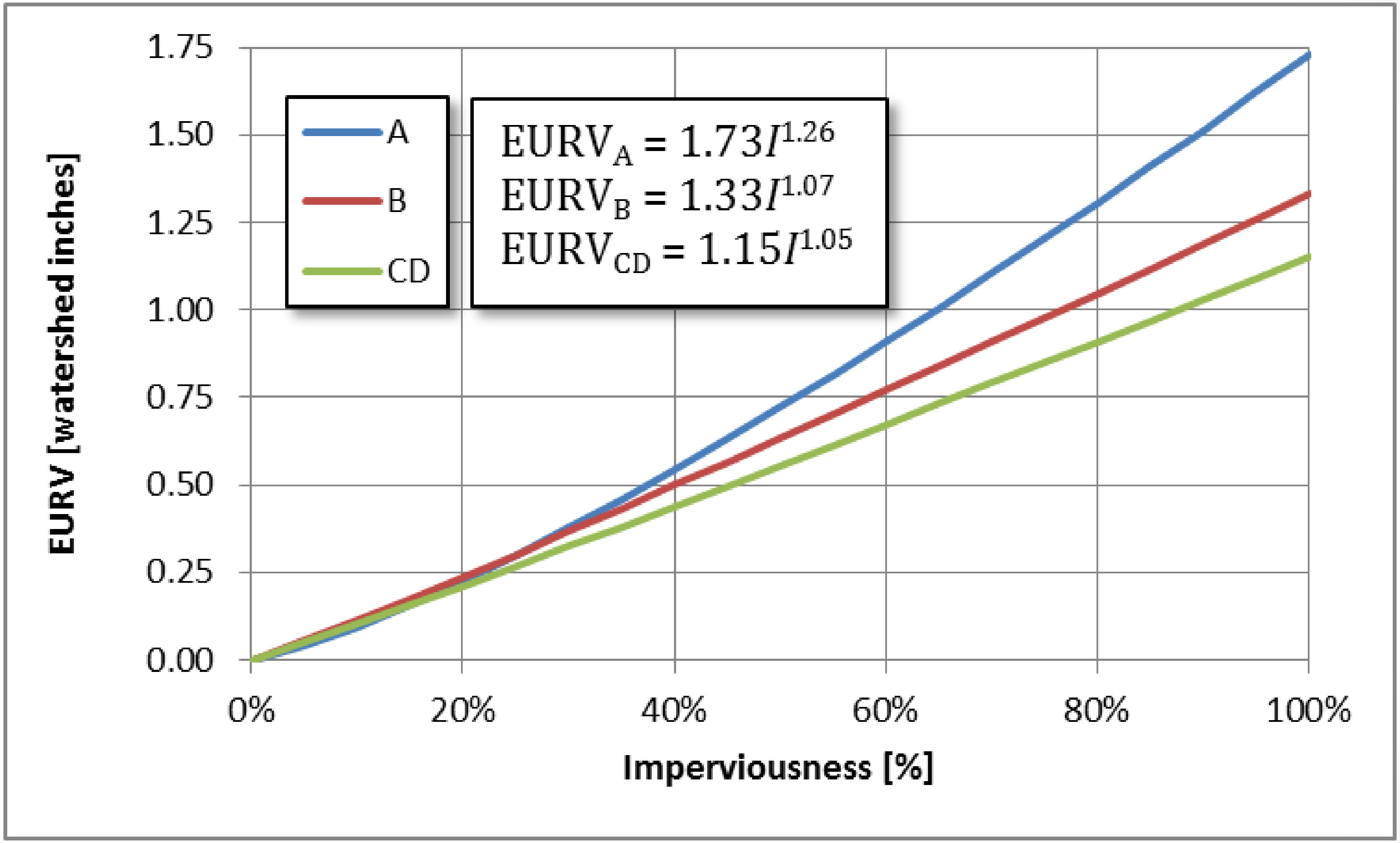
$$EURV_{HSG\ A} = 1.73(IMP)^{1.26}$$



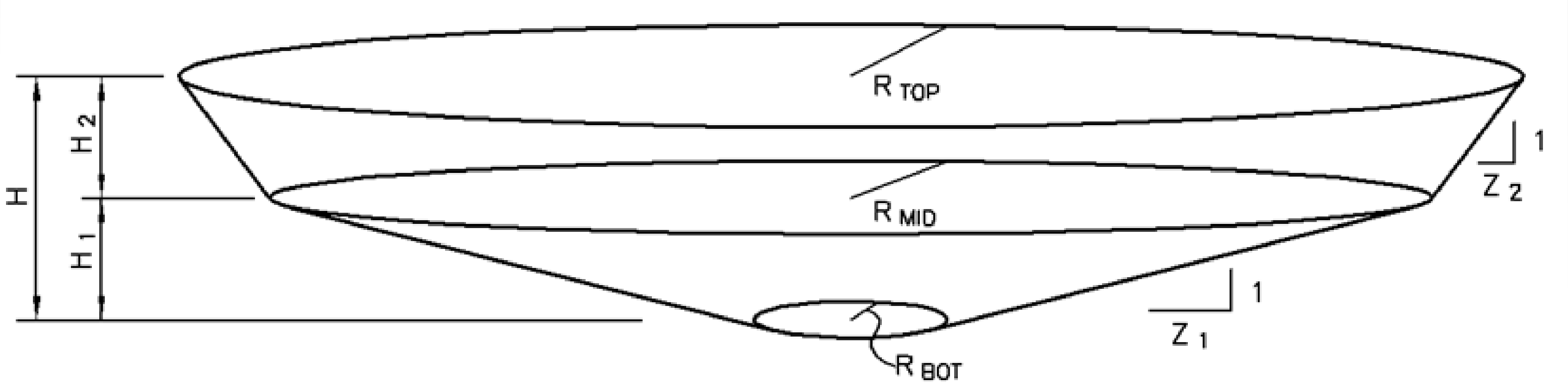
$$EURV_{HSG\ B} = 1.33(IMP)^{1.07}$$



$$EURV_{HSG\ C/D} = 1.15(IMP)^{1.05}$$



$$\mathrm{EURV}_A = 1.73 I^{1.26}$$
$$\mathrm{EURV}_B = 1.33 I^{1.07}$$
$$\mathrm{EURV}_{CD} = 1.15 I^{1.05}$$

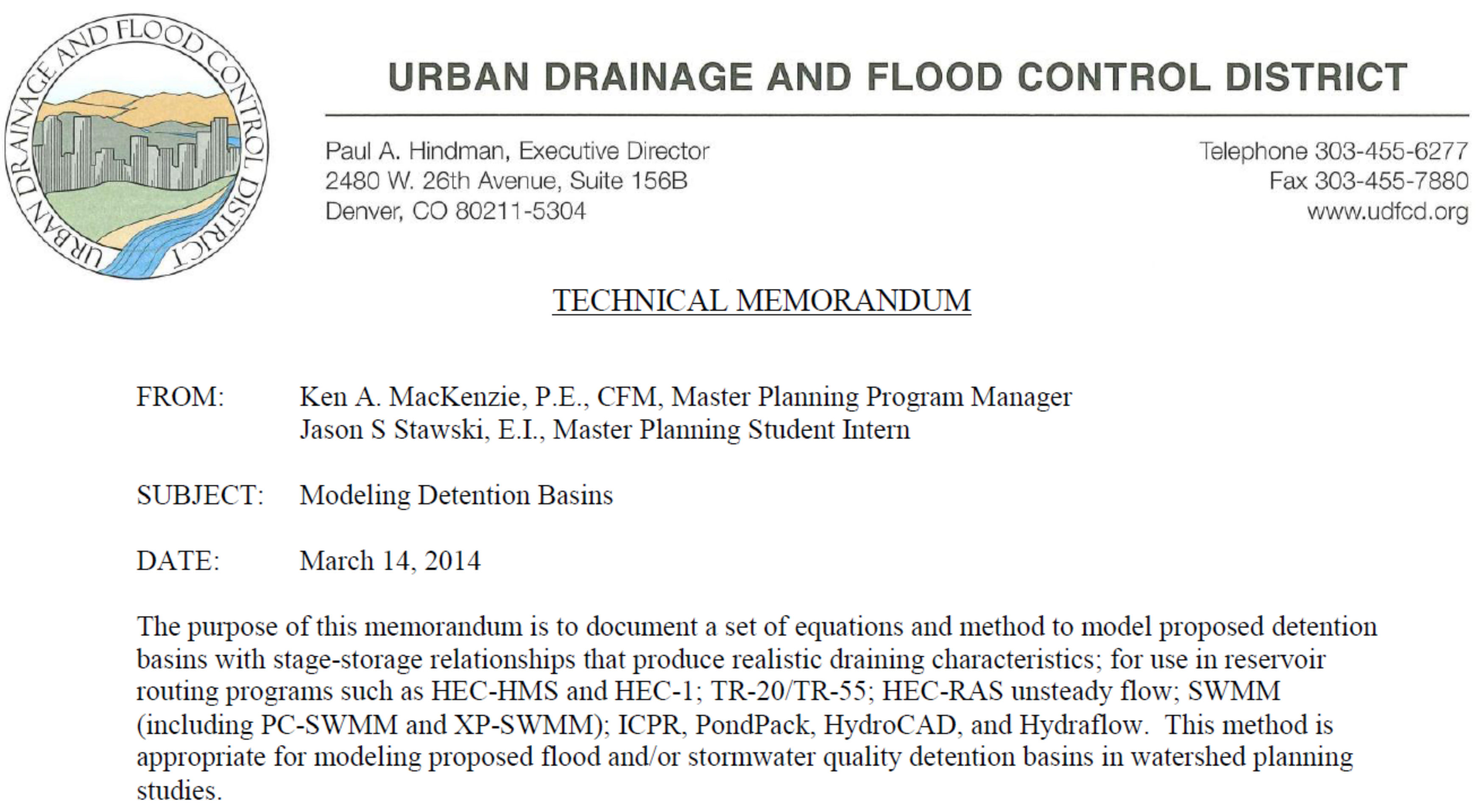


$$V_{LOWER} = \frac{H_1}{3}\left(A_{MID} + A_{BOT} + \sqrt{A_{MID}A_{BOT}}\right)$$

$$V_{UPPER} = \frac{H_2}{3}\left(A_{MID} + A_{TOP} + \sqrt{A_{MID}A_{TOP}}\right)$$

$$V_{COMPOSITE} = V_{LOWER} + V_{UPPER}$$

Basic Detention Basin Model



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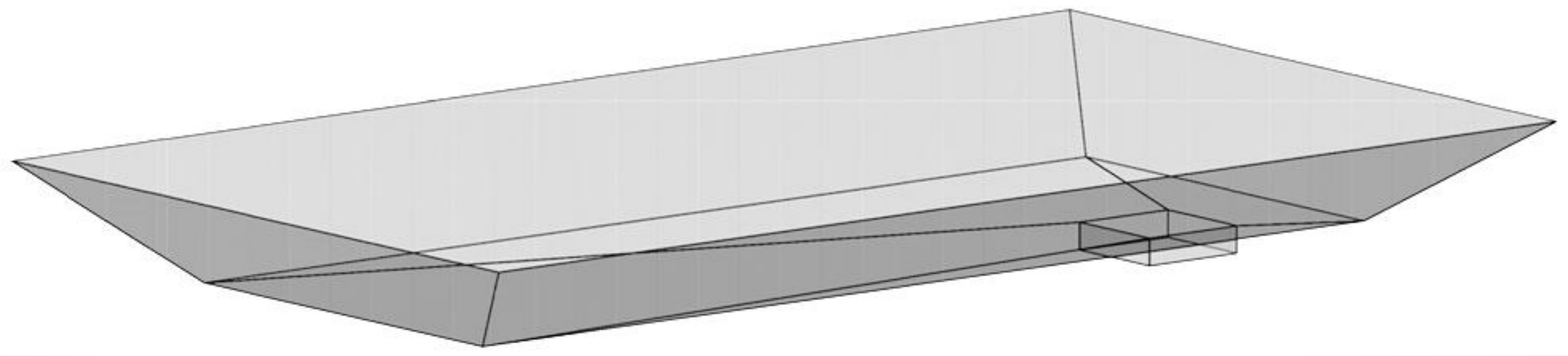
TECHNICAL MEMORANDUM

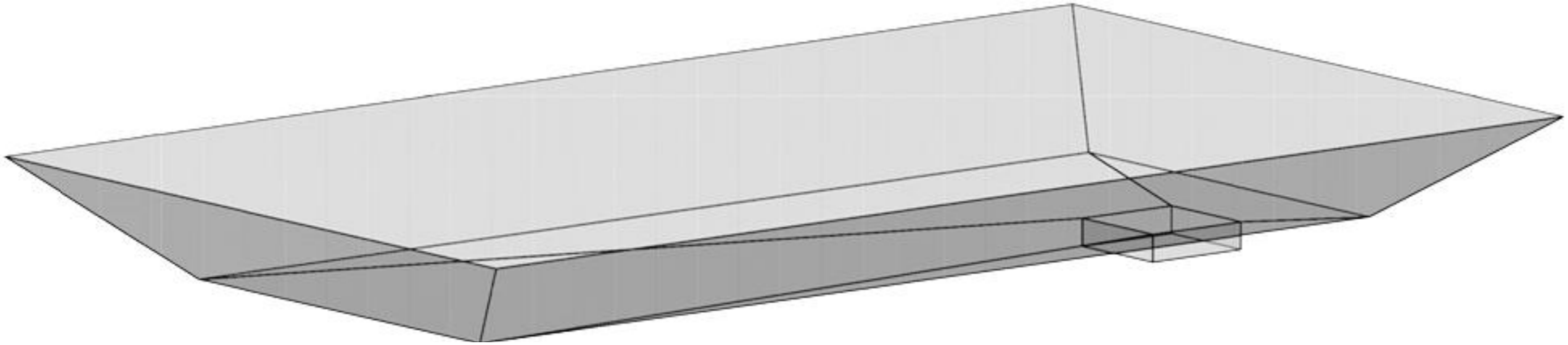
FROM: Ken A. MacKenzie, P.E., CFM, Master Planning Program Manager
Jason S Stawski, E.I., Master Planning Student Intern

SUBJECT: Modeling Detention Basins

DATE: March 14, 2014

The purpose of this memorandum is to document a set of equations and method to model proposed detention basins with stage-storage relationships that produce realistic draining characteristics; for use in reservoir routing programs such as HEC-HMS and HEC-1; TR-20/TR-55; HEC-RAS unsteady flow; SWMM (including PC-SWMM and XP-SWMM); ICPR, PondPack, HydroCAD, and Hydraflow. This method is appropriate for modeling proposed flood and/or stormwater quality detention basins in watershed planning studies.





Initial Surcharge Volume:

$$ISV = 0.003WQCV; \quad A_{ISV} = \frac{ISV}{ISD}; \quad L_{ISV} = \sqrt{A_{ISV}}; \quad W_{ISV} = \sqrt{A_{ISV}}$$

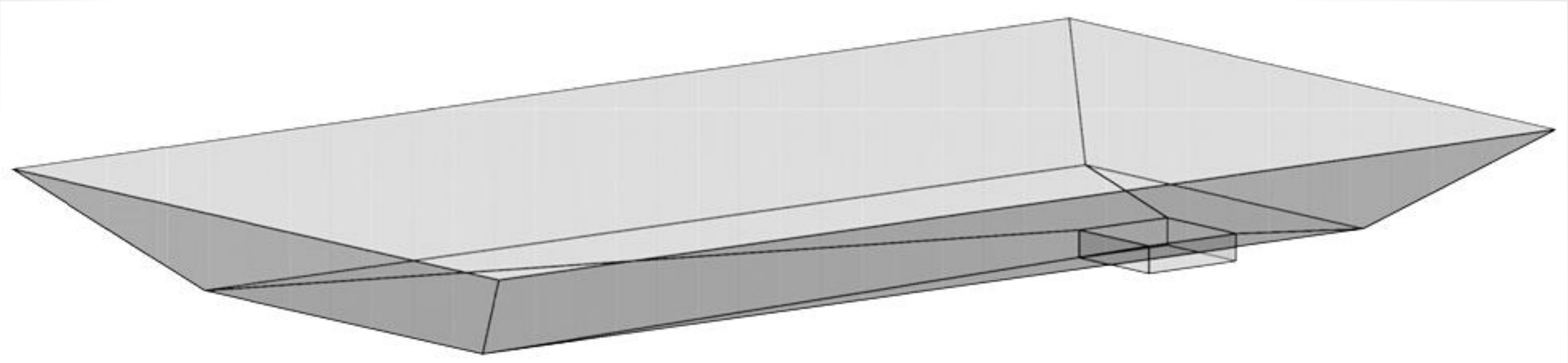
Where ISV is the initial surcharge volume (ft^3), A_{ISV} is ISV surface area (ft^2), ISD is the initial surcharge depth (ft, typically 0.33 to 0.50), and L_{ISV} and W_{ISV} are the length and width of the ISV (ft).

Basin Floor Volume:

$$L_{floor} = L_{ISV} + \frac{H_{floor}}{S_{TC}} + H_{floor}(S_{main}); \quad W_{floor} = W_{ISV} + \frac{H_{floor}}{R_{L:W}(S_{TC})};$$

$$A_{floor} = L_{floor}(W_{floor}); \quad V_{floor} = \frac{H_{floor}}{3}\left(A_{ISV} + A_{floor} + \sqrt{A_{ISV}(A_{floor})}\right)$$

Where L_{floor} and W_{floor} (ft) are the length and width of the basin floor section at the point where the top of the basin floor section meets the toe of the basin main section, H_{floor} is the depth of the basin floor section (ft), S_{TC} is the trickle channel slope (ft/ft), S_{main} is the side slope of the basin main section (H:V; e.g., 4 if the horizontal:vertical ratio is 4:1), $R_{L:W}$ is the basin length:width ratio (e.g., 2 if the basin length is twice the basin width), A_{floor} is top area of the basin floor section (ft^2), and V_{floor} is volume of the basin floor section (ft^3).



Main Basin Volume:

$L_{main} = L_{floor} + 2H_{main}(S_{main})$; $W_{main} = W_{floor} + 2H_{main}(S_{main})$; $A_{main} = L_{main}(W_{main})$;

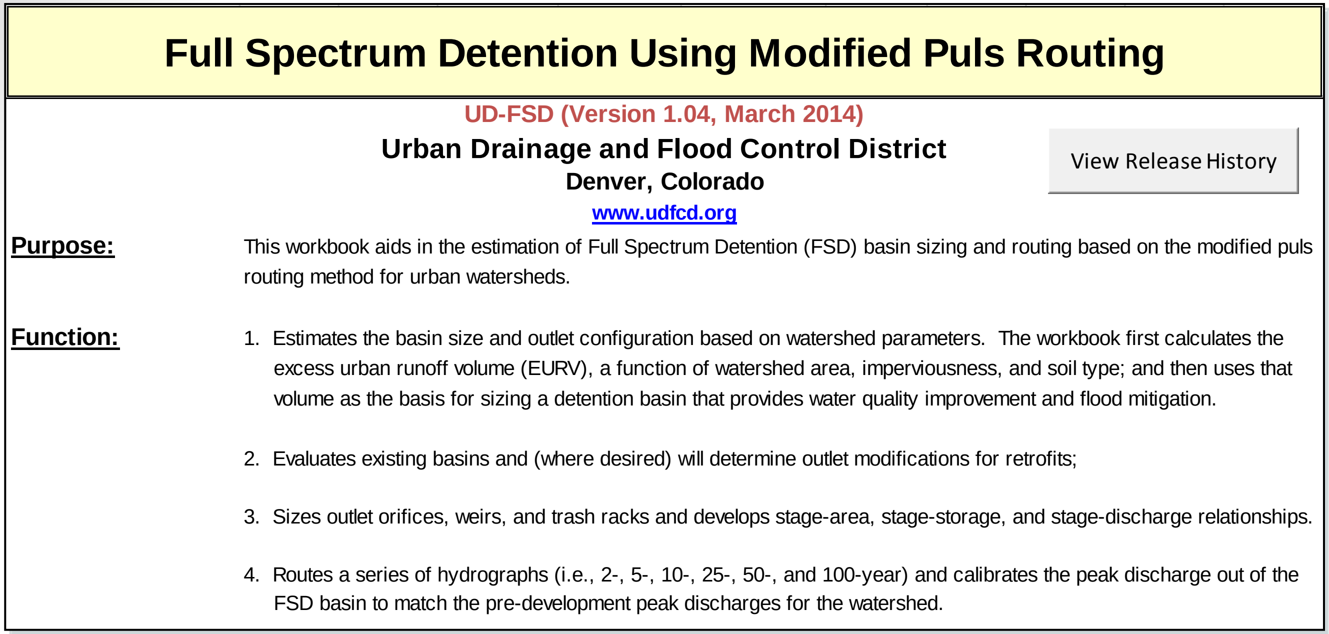
$$V_{main} = \frac{H_{main}}{3}\left(A_{main} + A_{floor} + \sqrt{A_{main}(A_{floor})}\right)$$

Where L_{main} and W_{main} (ft) are the length and width of the main basin section at the point at the top of the basin, H_{main} is the depth of the main basin section (ft), A_{main} is top area of the main basin section (ft^2), and V_{main} is volume of the main basin section (ft^3).

Total Basin Volume:

$V_{total} = ISV + V_{floor} + V_{main}$

Where V_{total} is the total basin volume (ft^3).



Full Spectrum Detention Using Modified Puls Routing

UD-FSD (Version 1.04, March 2014)

Urban Drainage and Flood Control District

Denver, Colorado

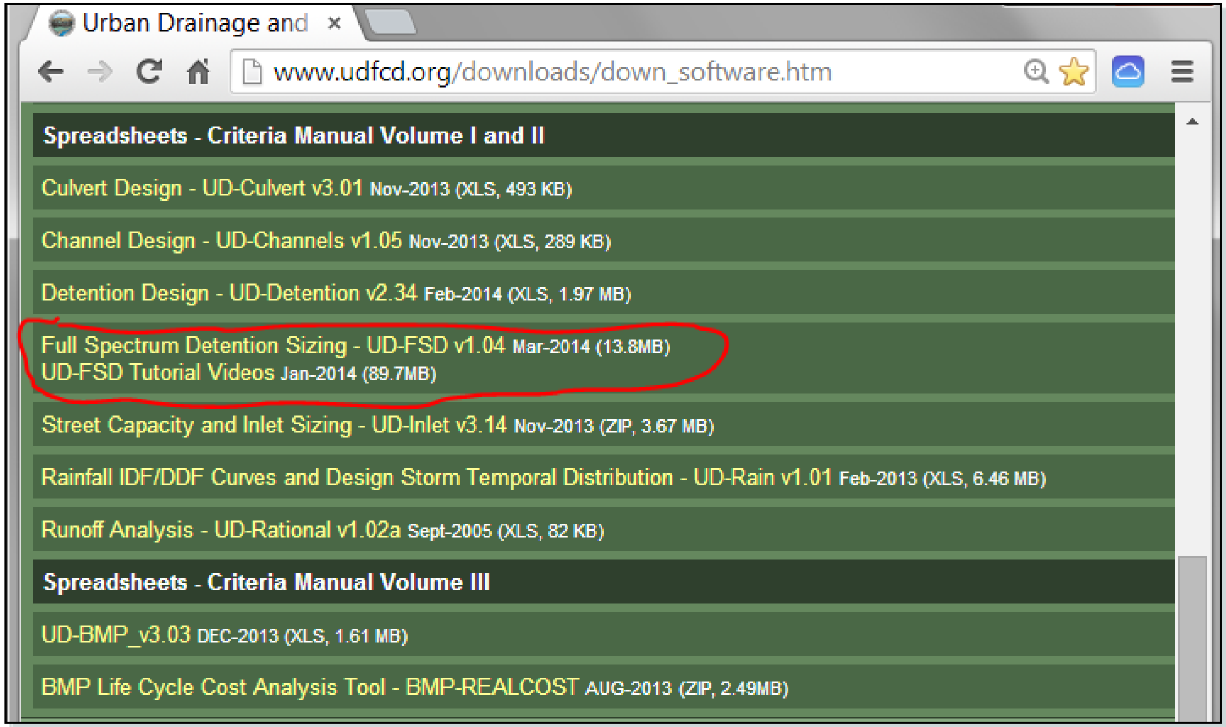
www.udfcd.org

View Release History

Purpose: This workbook aids in the estimation of Full Spectrum Detention (FSD) basin sizing and routing based on the modified puls routing method for urban watersheds.

Function:

1. Estimates the basin size and outlet configuration based on watershed parameters. The workbook first calculates the excess urban runoff volume (EURV), a function of watershed area, imperviousness, and soil type; and then uses that volume as the basis for sizing a detention basin that provides water quality improvement and flood mitigation.
2. Evaluates existing basins and (where desired) will determine outlet modifications for retrofits;
3. Sizes outlet orifices, weirs, and trash racks and develops stage-area, stage-storage, and stage-discharge relationships.
4. Routes a series of hydrographs (i.e., 2-, 5-, 10-, 25-, 50-, and 100-year) and calibrates the peak discharge out of the FSD basin to match the pre-development peak discharges for the watershed.



Spreadsheets - Criteria Manual Volume I and II

Culvert Design - UD-Culvert v3.01 Nov-2013 (XLS, 493 KB)

Channel Design - UD-Channels v1.05 Nov-2013 (XLS, 289 KB)

Detention Design - UD-Detention v2.34 Feb-2014 (XLS, 1.97 MB)

Full Spectrum Detention Sizing - UD-FSD v1.04 Mar-2014 (13.8MB)
UD-FSD Tutorial Videos Jan-2014 (89.7MB)

Street Capacity and Inlet Sizing - UD-Inlet v3.14 Nov-2013 (ZIP, 3.67 MB)

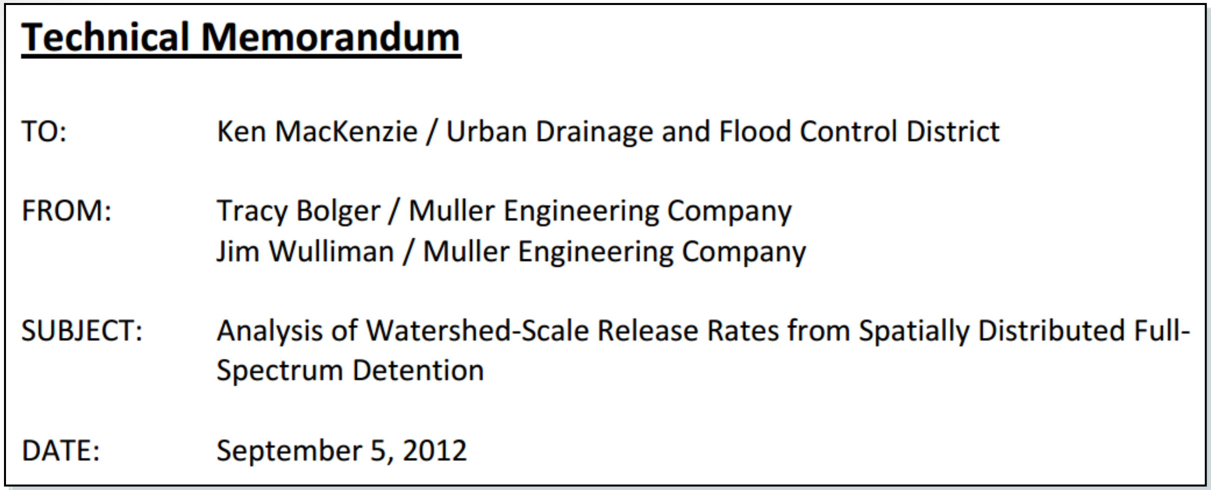
Rainfall IDF/DDF Curves and Design Storm Temporal Distribution - UD-Rain v1.01 Feb-2013 (XLS, 6.46 MB)

Runoff Analysis - UD-Rational v1.02a Sept-2005 (XLS, 82 KB)

Spreadsheets - Criteria Manual Volume III

UD-BMP_v3.03 DEC-2013 (XLS, 1.61 MB)

BMP Life Cycle Cost Analysis Tool - BMP-REALCOST AUG-2013 (ZIP, 2.49MB)



Technical Memorandum

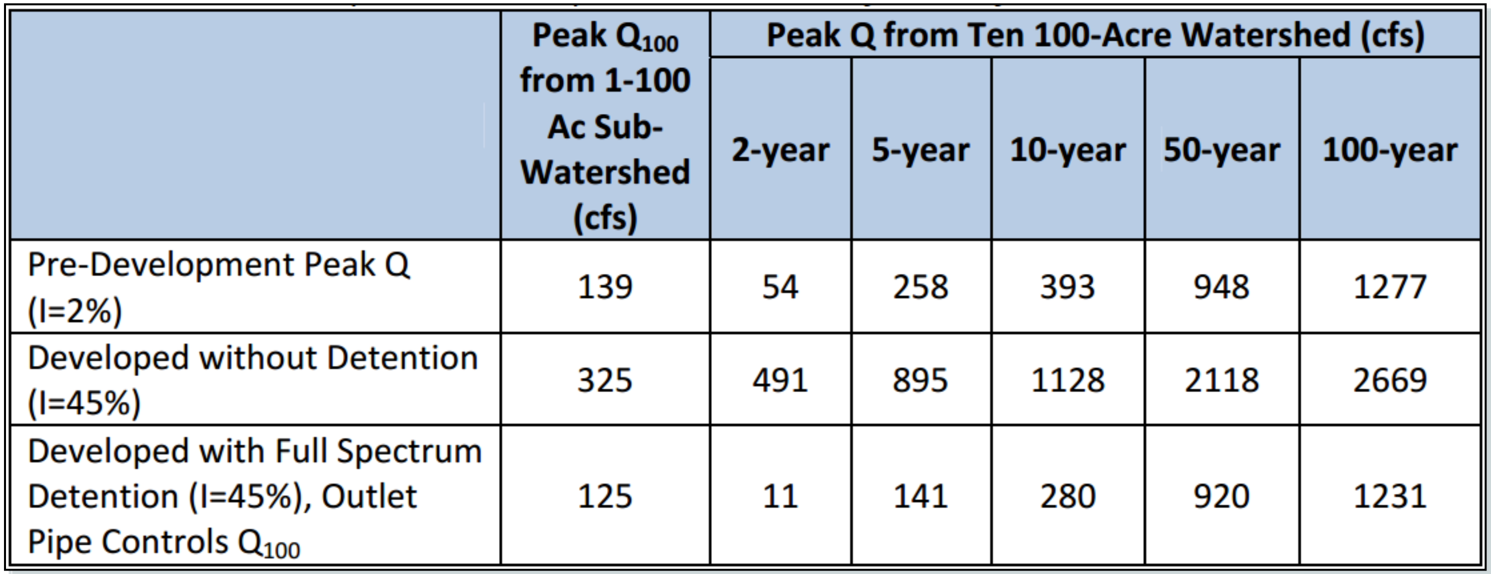
TO: Ken MacKenzie / Urban Drainage and Flood Control District

FROM: Tracy Bolger / Muller Engineering Company
Jim Wulliman / Muller Engineering Company

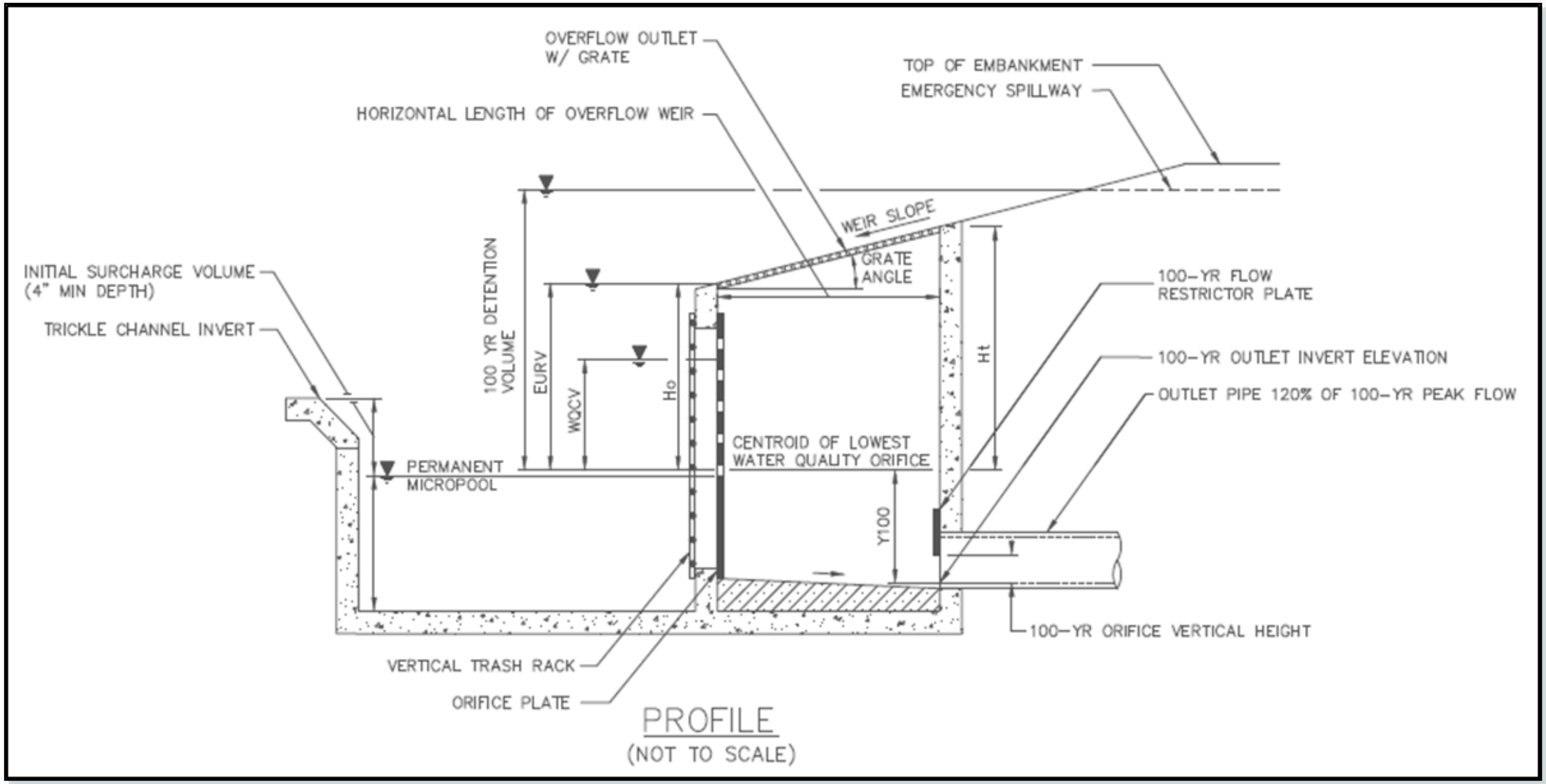
SUBJECT: Analysis of Watershed-Scale Release Rates from Spatially Distributed Full-Spectrum Detention

DATE: September 5, 2012

Bolger & Wulliman determined that in order to restore the peak flow rate to pre-developed levels in a large watershed, each subcatchment must release at no more than 90% of its pre-developed peak flow rate.

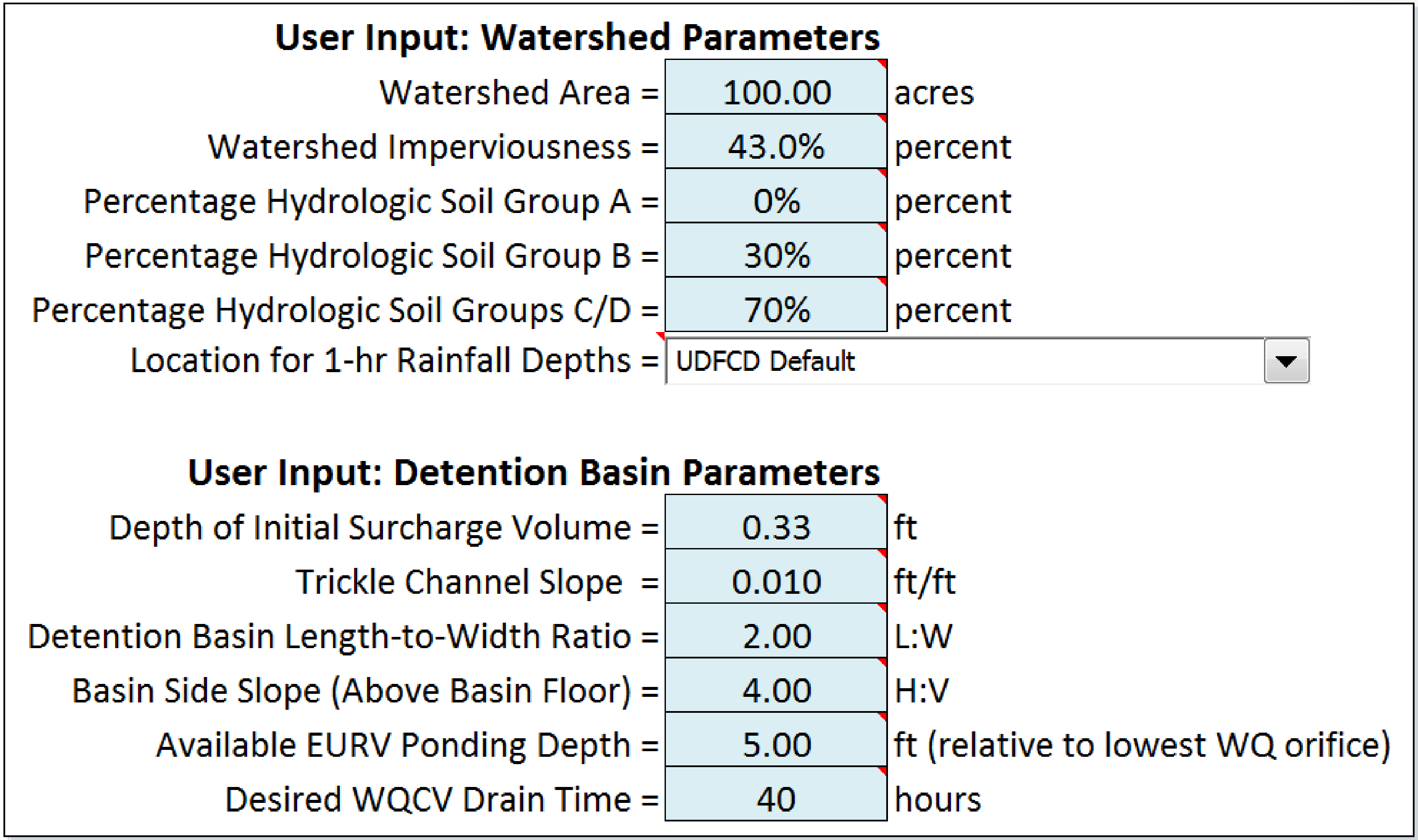


	Peak Q_{100} from 1-100 Ac Sub-Watershed (cfs)	Peak Q from Ten 100-Acre Watershed (cfs)				
		2-year	5-year	10-year	50-year	100-year
Pre-Development Peak Q (I=2%)	139	54	258	393	948	1277
Developed without Detention (I=45%)	325	491	895	1128	2118	2669
Developed with Full Spectrum Detention (I=45%), Outlet Pipe Controls Q_{100}	125	11	141	280	920	1231



PROFILE
(NOT TO SCALE)

Initial Design for Full Spectrum Detention Basins



User Input: Watershed Parameters

Watershed Area = 100.00 acres

Watershed Imperviousness = 43.0% percent

Percentage Hydrologic Soil Group A = 0% percent

Percentage Hydrologic Soil Group B = 30% percent

Percentage Hydrologic Soil Groups C/D = 70% percent

Location for 1-hr Rainfall Depths = UDFCD Default

User Input: Detention Basin Parameters

Depth of Initial Surcharge Volume = 0.33 ft

Trickle Channel Slope = 0.010 ft/ft

Detention Basin Length-to-Width Ratio = 2.00 L:W

Basin Side Slope (Above Basin Floor) = 4.00 H:V

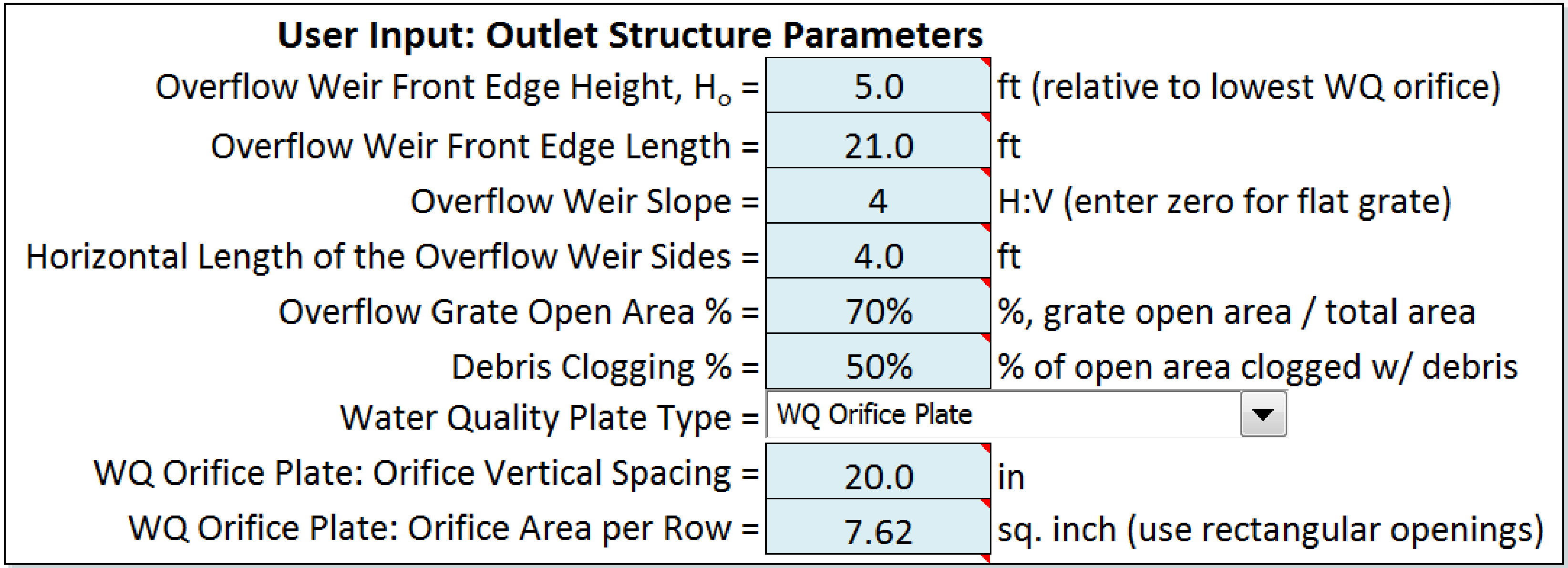
Available EURV Ponding Depth = 5.00 ft (relative to lowest WQ orifice)

Desired WQCV Drain Time = 40 hours

UD-FSD One-Hour Rainfall Choices:

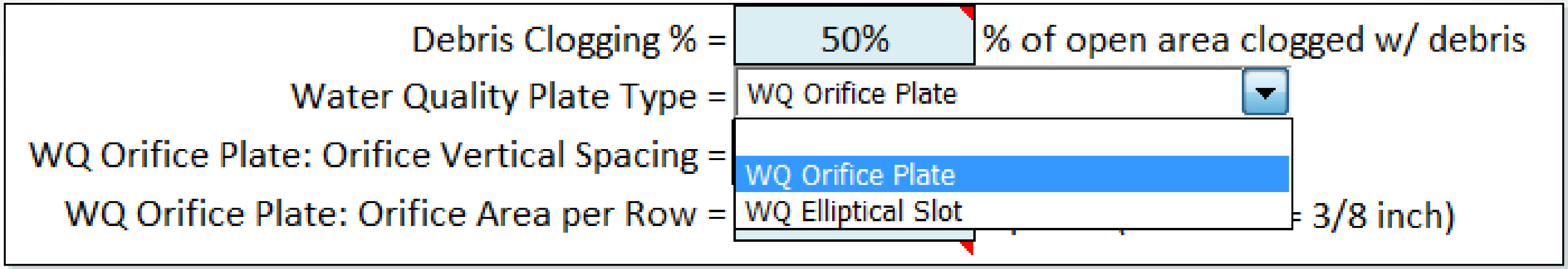
1. UDFCD Default
2. Aurora - Town Center at Aurora
3. Aurora Reservoir
4. Boulder - University of Colorado
5. Brighton - Brighton City Hall
6. Broomfield - Broomfield City Manager
7. Commerce City
8. D.I.A.
9. Denver - Capitol Hill
10. Eldorado Springs
11. Front Range Airport
12. Golden - School of Mines
13. Greenwood Village - Greenwood Village City Hall
14. Highlands Ranch - Highlands Ranch Mansion
15. Ken Caryl - Chatfield High School
16. Lakewood - Lakewood Cultural Center
17. Littleton - Arapahoe Community College
18. Morrison - Red Rocks Amphitheater
19. Parker - Parker Town Court
20. Roxborough Park
21. Sedalia
22. Thornton - Thornton City Office
23. Westminster - Westminster City Hall

Initial Design for Full Spectrum Detention Basins



User Input: Outlet Structure Parameters

Overflow Weir Front Edge Height, H_o =	5.0	ft (relative to lowest WQ orifice)
Overflow Weir Front Edge Length =	21.0	ft
Overflow Weir Slope =	4	H:V (enter zero for flat grate)
Horizontal Length of the Overflow Weir Sides =	4.0	ft
Overflow Grate Open Area % =	70%	%, grate open area / total area
Debris Clogging % =	50%	% of open area clogged w/ debris
Water Quality Plate Type =	WQ Orifice Plate ▼	
WQ Orifice Plate: Orifice Vertical Spacing =	20.0	in
WQ Orifice Plate: Orifice Area per Row =	7.62	sq. inch (use rectangular openings)

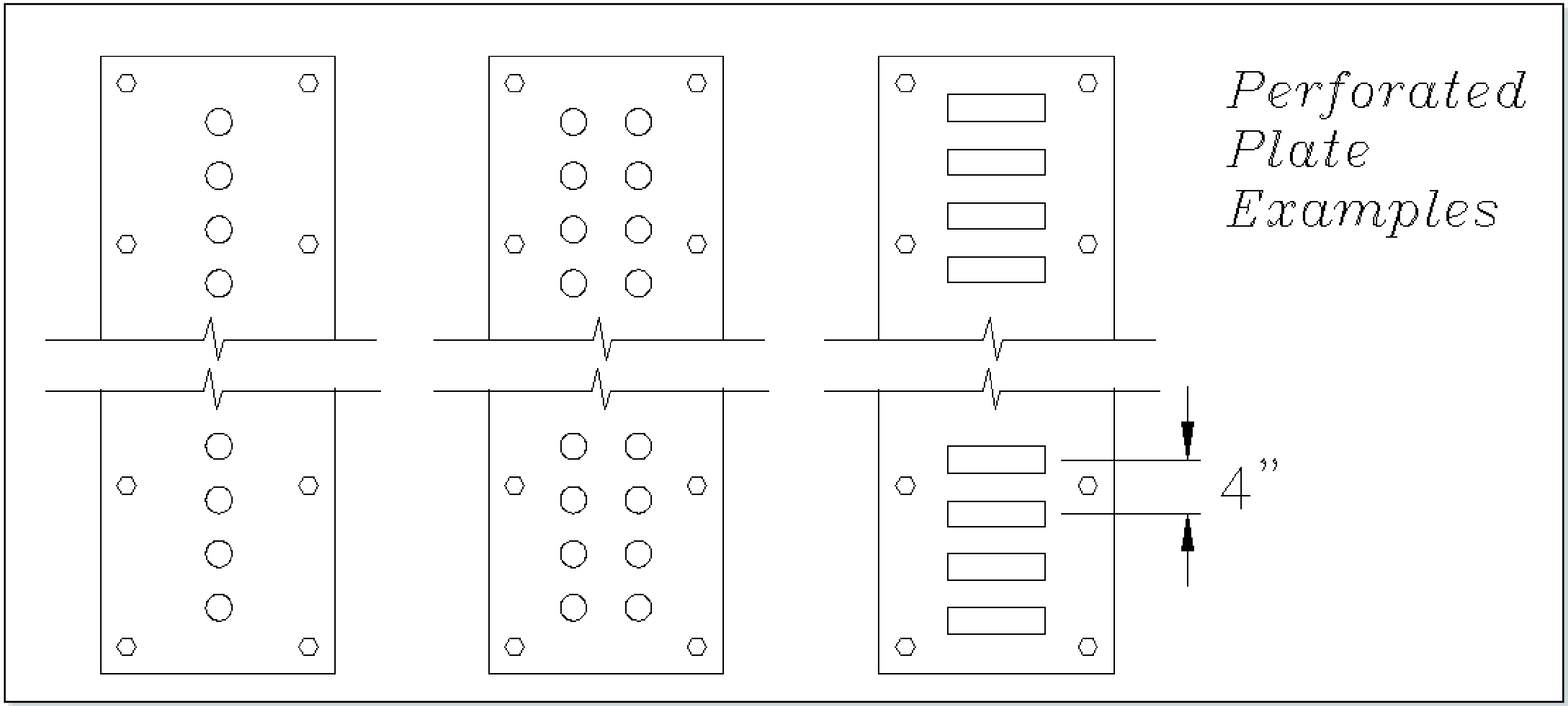


Debris Clogging % = 50% % of open area clogged w/ debris

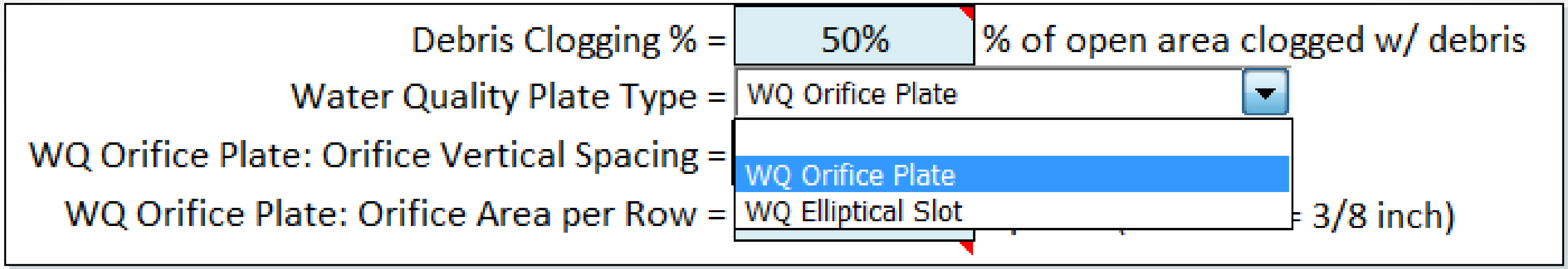
Water Quality Plate Type = WQ Orifice Plate

WQ Orifice Plate: Orifice Vertical Spacing =

WQ Orifice Plate: Orifice Area per Row = 3/8 inch)



Perforated Plate Examples

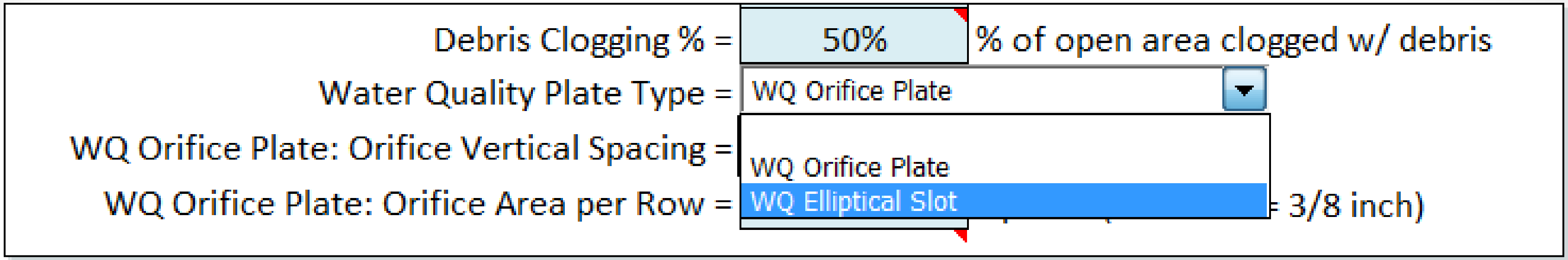


Debris Clogging % = 50% % of open area clogged w/ debris

Water Quality Plate Type = WQ Orifice Plate

WQ Orifice Plate: Orifice Vertical Spacing =

WQ Orifice Plate: Orifice Area per Row = = 3/8 inch)



Debris Clogging % = 50% % of open area clogged w/ debris

Water Quality Plate Type = WQ Orifice Plate

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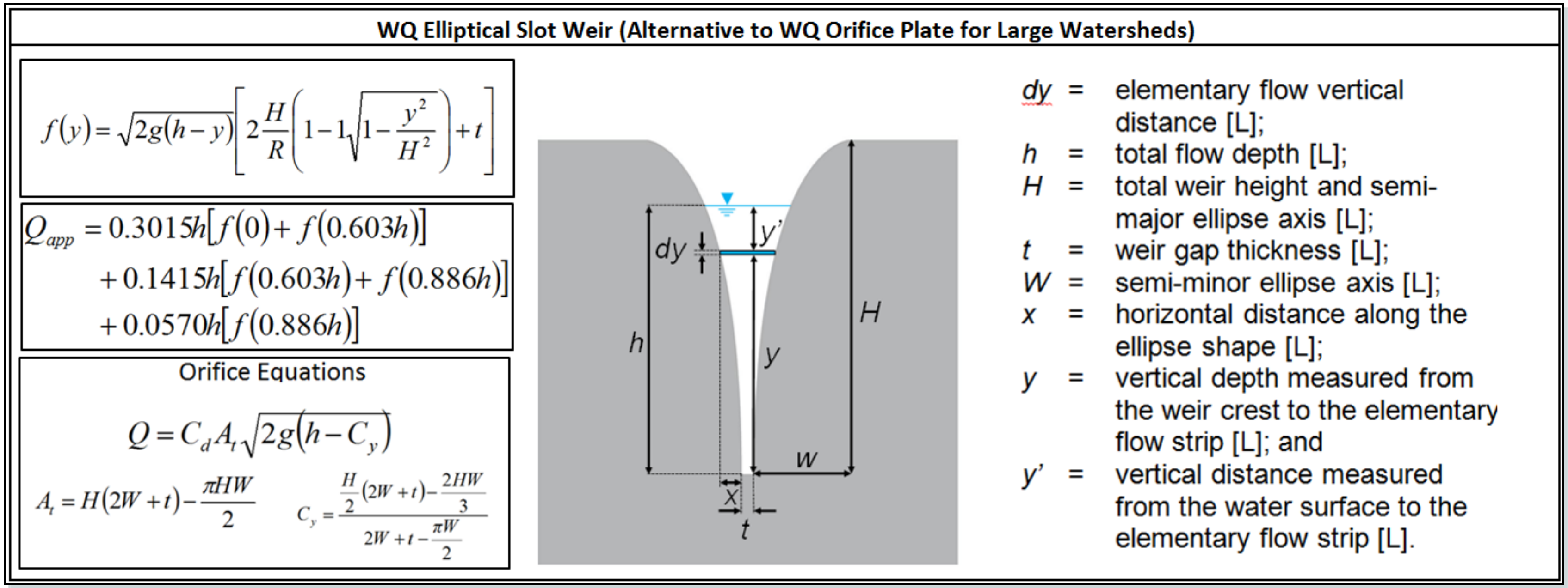


WQ Elliptical Slot Weir (Alternative to WQ Orifice Plate for Large Watersheds)

$$f(y)=\sqrt{2g(h-y)}\left[2\frac{H}{R}\left(1-1\sqrt{1-\frac{y^2}{H^2}}\right)+t\right]$$

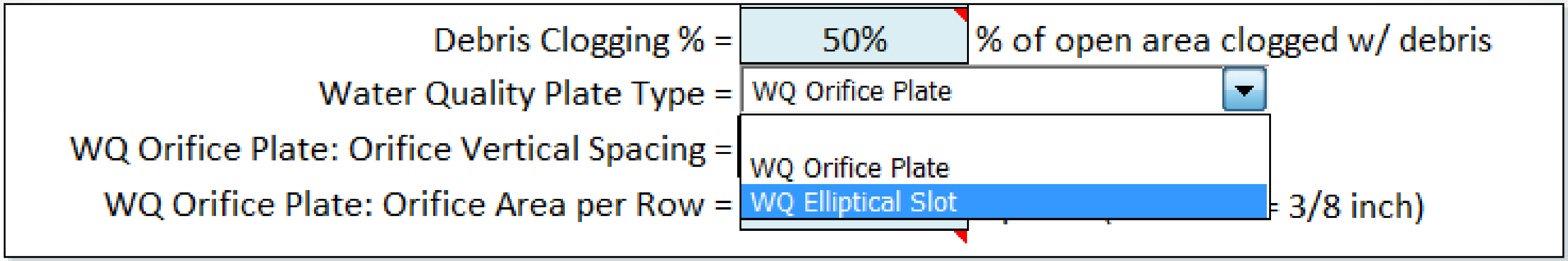
$$\begin{aligned}Q_{app} &= 0.3015h\left[f(0)+f(0.603h)\right]\\ &+0.1415h\left[f(0.603h)+f(0.886h)\right]\\ &+0.0570h\left[f(0.886h)\right]\end{aligned}$$

Orifice Equations

$$Q=C_dA_t\sqrt{2g(h-C_y)}$$

$$A_t=H(2W+t)-\frac{\pi HW}{2} \qquad C_y=\frac{\frac{H}{2}(2W+t)-\frac{2HW}{3}}{2W+t-\frac{\pi W}{2}}$$

dy = elementary flow vertical distance [L];
h = total flow depth [L];
H = total weir height and semi-major ellipse axis [L];
t = weir gap thickness [L];
W = semi-minor ellipse axis [L];
x = horizontal distance along the ellipse shape [L];
y = vertical depth measured from the weir crest to the elementary flow strip [L]; and
y' = vertical distance measured from the water surface to the elementary flow strip [L].



Debris Clogging % = 50% % of open area clogged w/ debris

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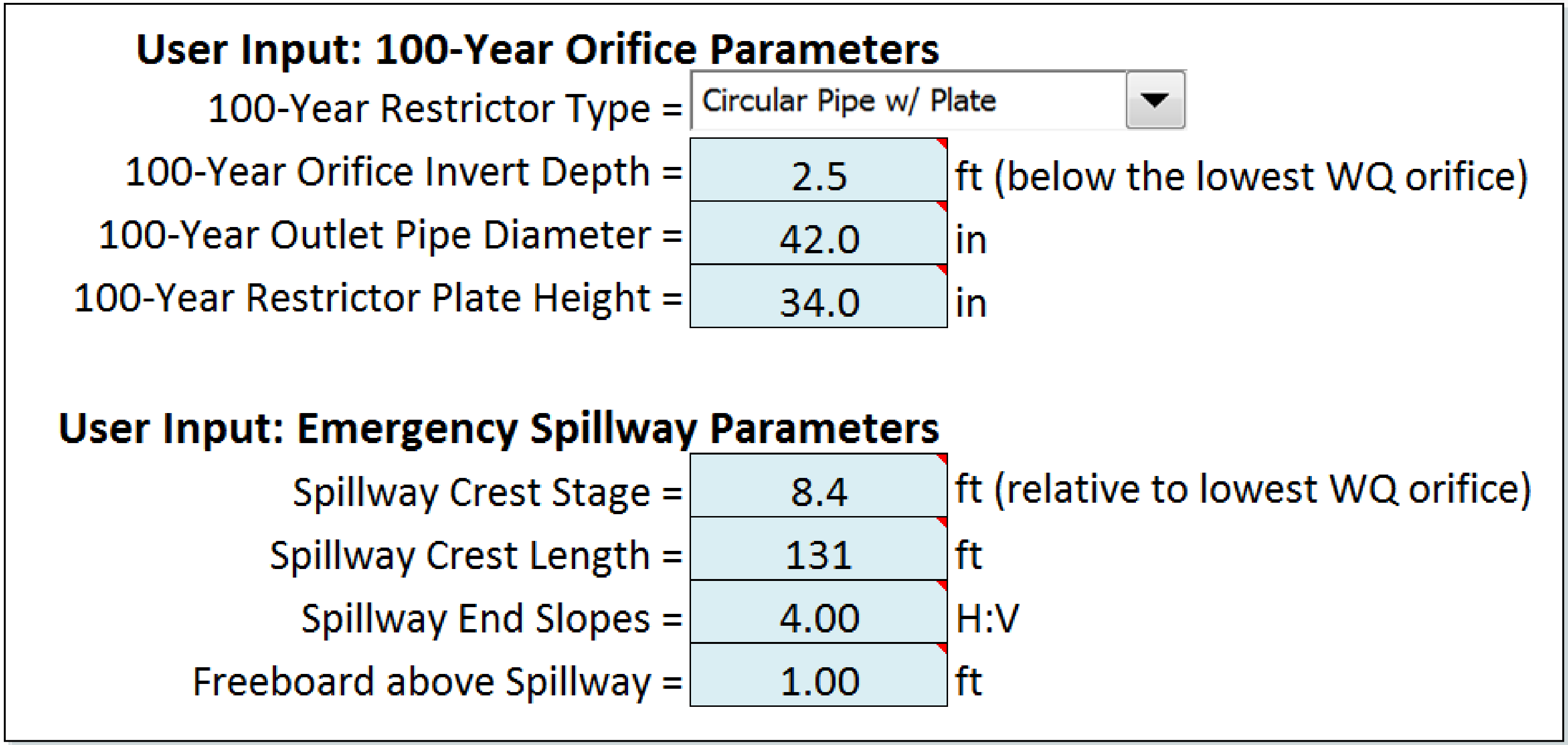


User Input: 100-Year Orifice Parameters

100-Year Restrictor Type = Circular Pipe w/ Plate

100-Year Orifice Invert Depth = 2.5 ft (below the lowest WQ orifice)

100-Year Outlet Pipe Diameter = 42.0 in

100-Year Restrictor Plate Height = 34.0 in

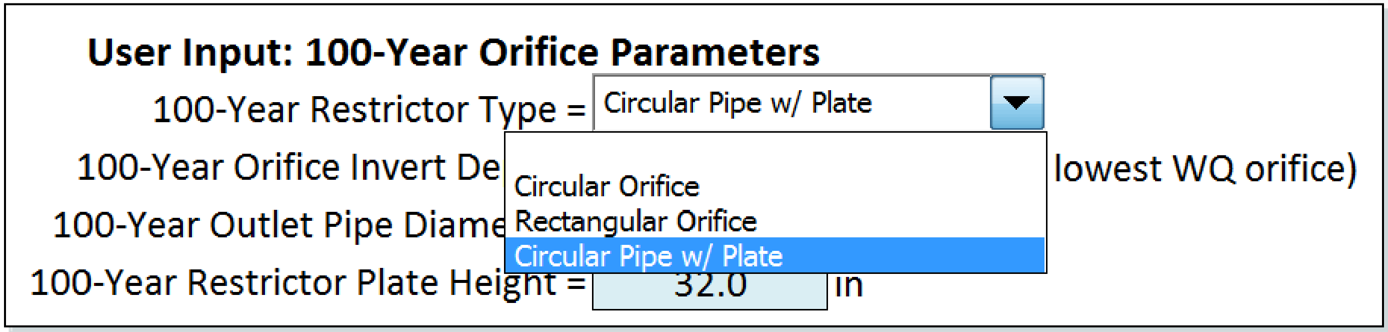
User Input: Emergency Spillway Parameters

Spillway Crest Stage = 8.4 ft (relative to lowest WQ orifice)

Spillway Crest Length = 131 ft

Spillway End Slopes = 4.00 H:V

Freeboard above Spillway = 1.00 ft



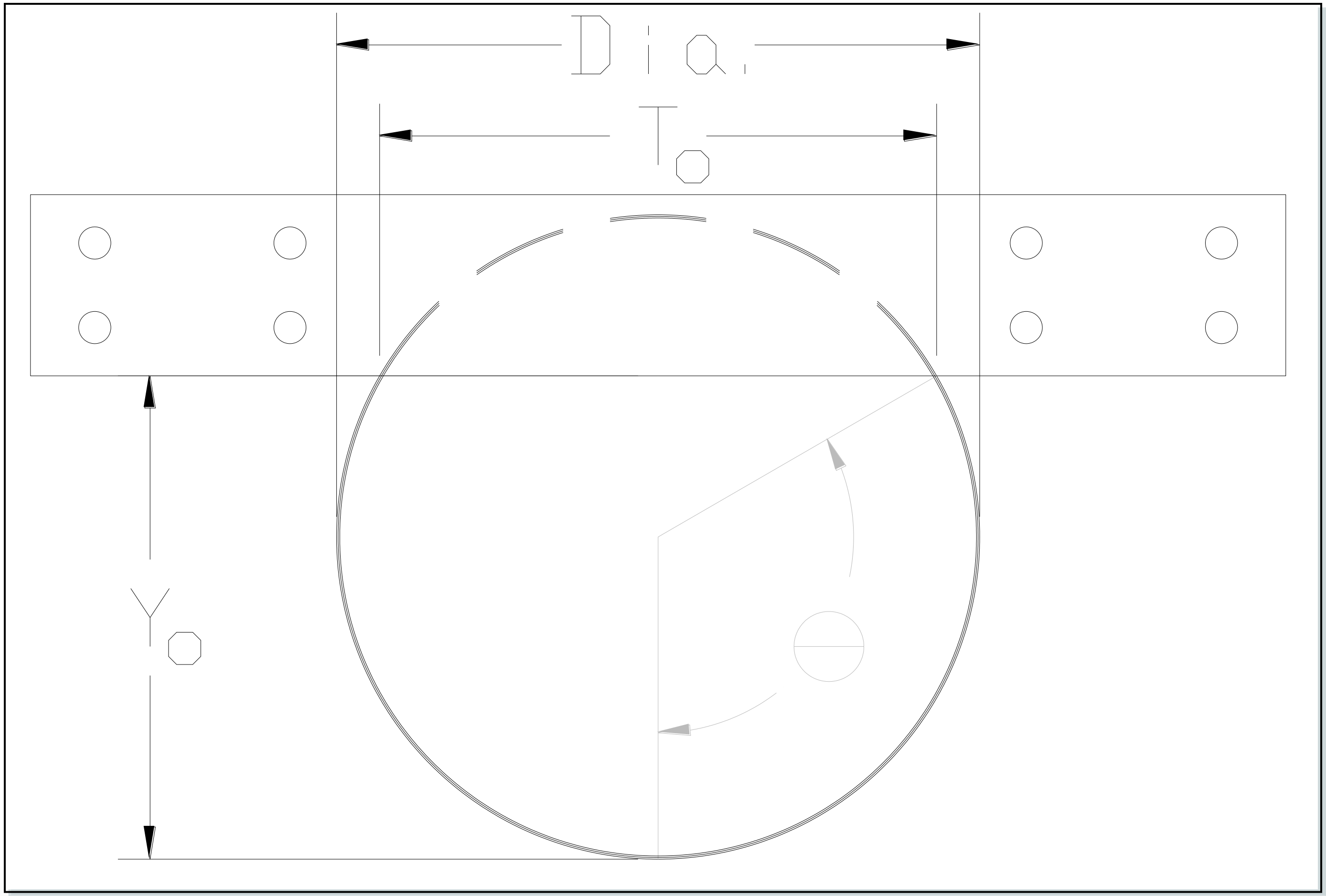
User Input: 100-Year Orifice Parameters

100-Year Restrictor Type = Circular Pipe w/ Plate

100-Year Orifice Invert De lowest WQ orifice)

100-Year Outlet Pipe Diame

100-Year Restrictor Plate Height = 32.0 in



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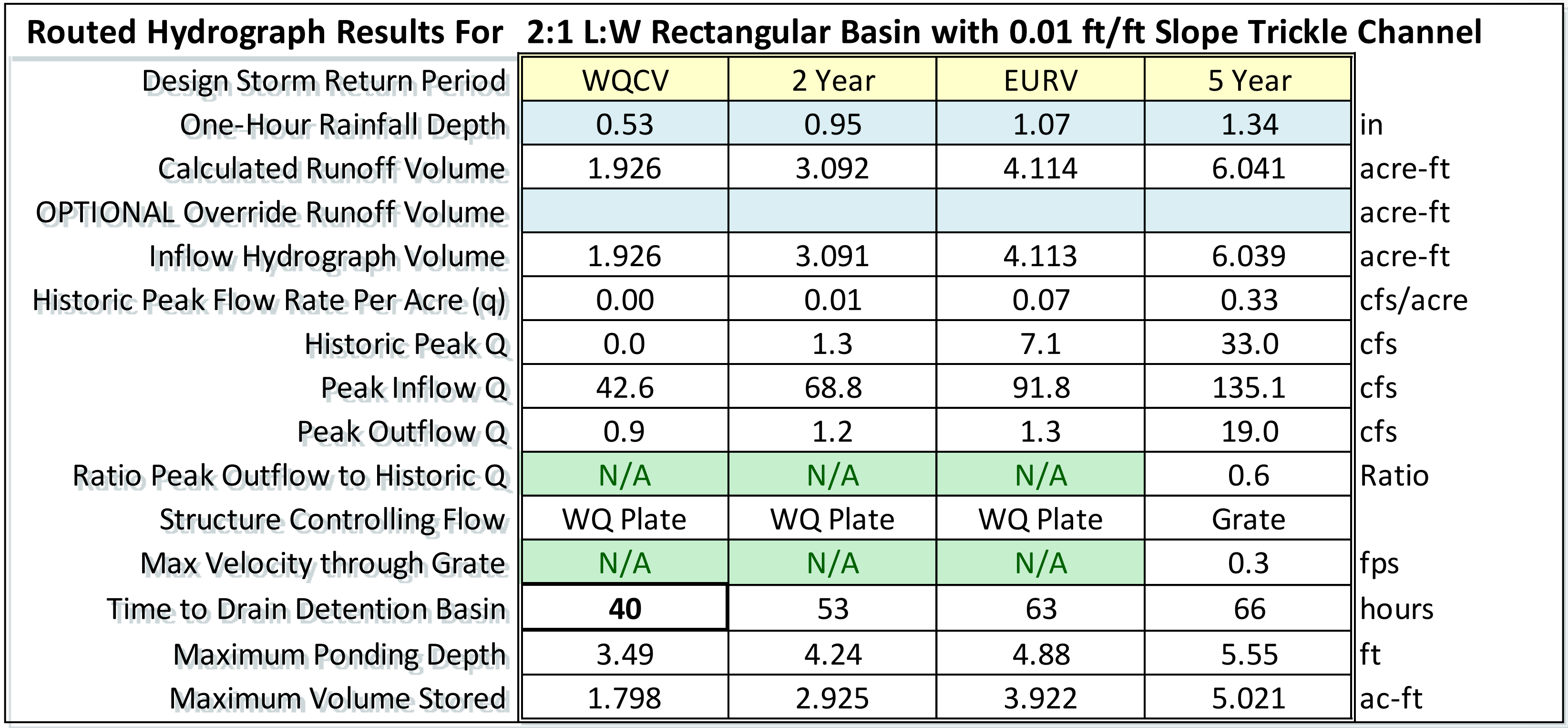

Routed Hydrograph Results For 2:1 L:W Rectangular Basin with 0.01 ft/ft Slope Trickle Channel

Design Storm Return Period	WQCV	2 Year	EURV	5 Year	
One-Hour Rainfall Depth	0.53	0.95	1.07	1.34	in
Calculated Runoff Volume	1.926	3.092	4.114	6.041	acre-ft
OPTIONAL Override Runoff Volume					acre-ft
Inflow Hydrograph Volume	1.926	3.091	4.113	6.039	acre-ft
Historic Peak Flow Rate Per Acre (q)	0.00	0.01	0.07	0.33	cfs/acre
Historic Peak Q	0.0	1.3	7.1	33.0	cfs
Peak Inflow Q	42.6	68.8	91.8	135.1	cfs
Peak Outflow Q	0.9	1.2	1.3	19.0	cfs
Ratio Peak Outflow to Historic Q	N/A	N/A	N/A	0.6	Ratio
Structure Controlling Flow	WQ Plate	WQ Plate	WQ Plate	Grate	
Max Velocity through Grate	N/A	N/A	N/A	0.3	fps
Time to Drain Detention Basin	**40**	53	63	66	hours
Maximum Ponding Depth	3.49	4.24	4.88	5.55	ft
Maximum Volume Stored	1.798	2.925	3.922	5.021	ac-ft

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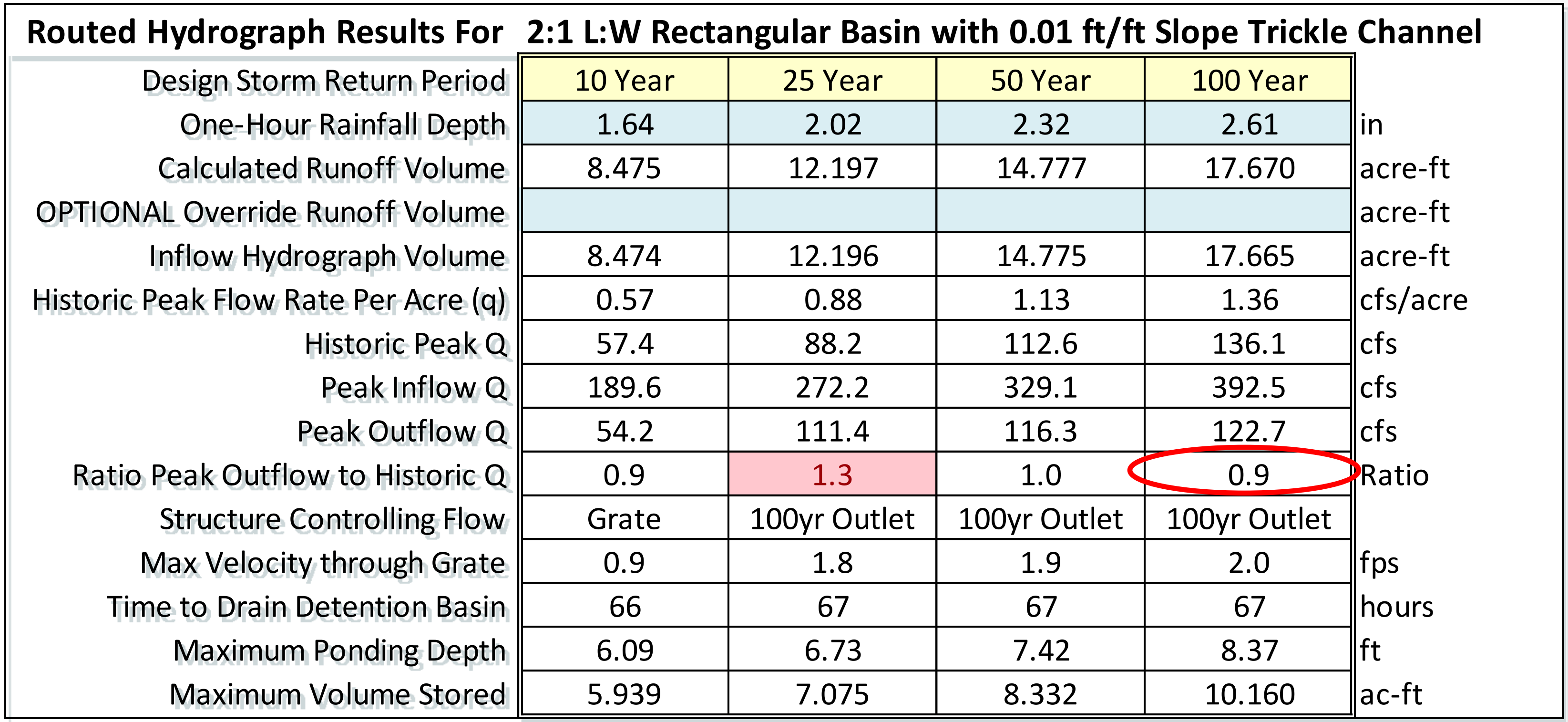

Routed Hydrograph Results For 2:1 L:W Rectangular Basin with 0.01 ft/ft Slope Trickle Channel

Design Storm Return Period	10 Year	25 Year	50 Year	100 Year	
One-Hour Rainfall Depth	1.64	2.02	2.32	2.61	in
Calculated Runoff Volume	8.475	12.197	14.777	17.670	acre-ft
OPTIONAL Override Runoff Volume					acre-ft
Inflow Hydrograph Volume	8.474	12.196	14.775	17.665	acre-ft
Historic Peak Flow Rate Per Acre (q)	0.57	0.88	1.13	1.36	cfs/acre
Historic Peak Q	57.4	88.2	112.6	136.1	cfs
Peak Inflow Q	189.6	272.2	329.1	392.5	cfs
Peak Outflow Q	54.2	111.4	116.3	122.7	cfs
Ratio Peak Outflow to Historic Q	0.9	1.3	1.0	0.9	Ratio
Structure Controlling Flow	Grate	100yr Outlet	100yr Outlet	100yr Outlet	
Max Velocity through Grate	0.9	1.8	1.9	2.0	fps
Time to Drain Detention Basin	66	67	67	67	hours
Maximum Ponding Depth	6.09	6.73	7.42	8.37	ft
Maximum Volume Stored	5.939	7.075	8.332	10.160	ac-ft

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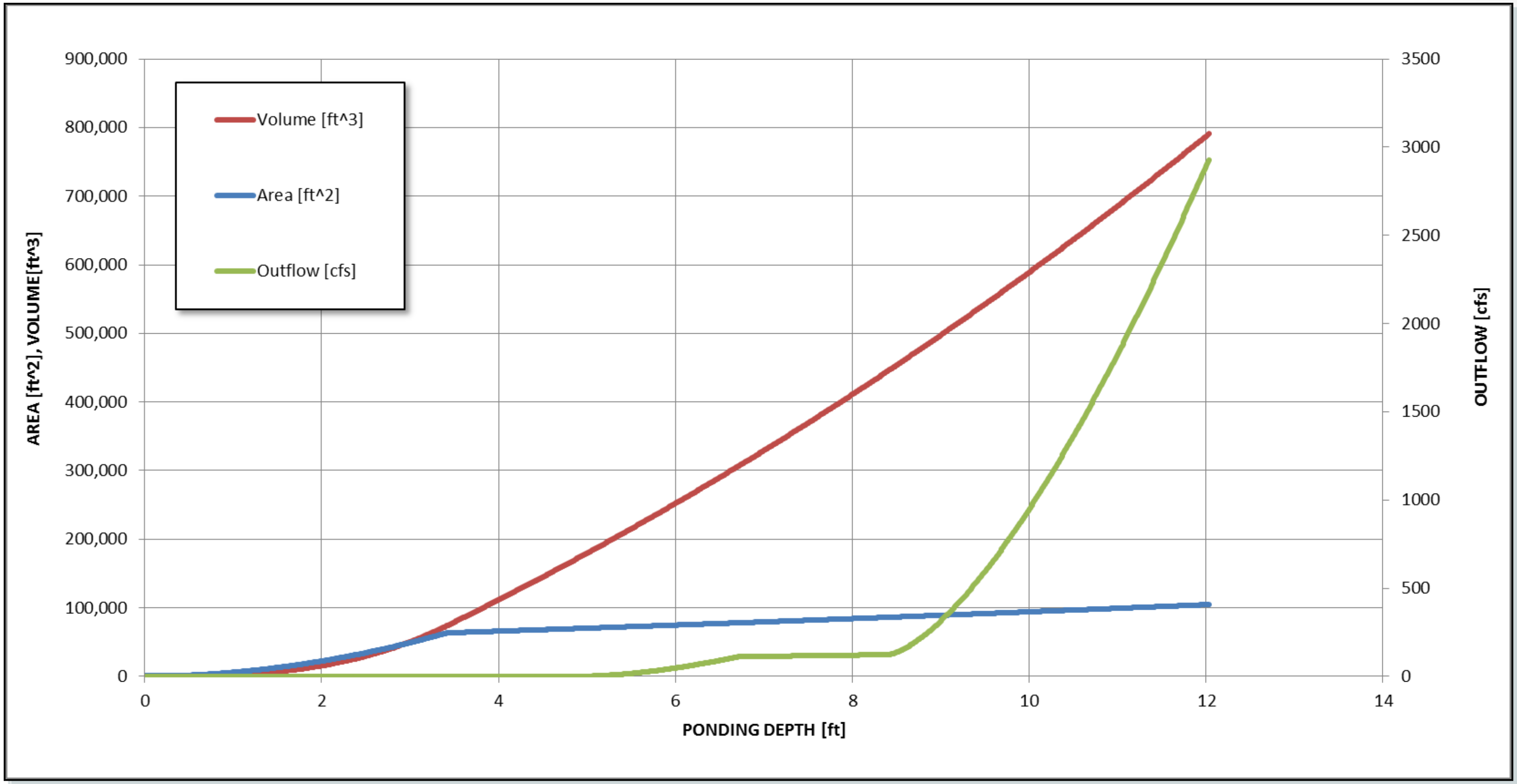

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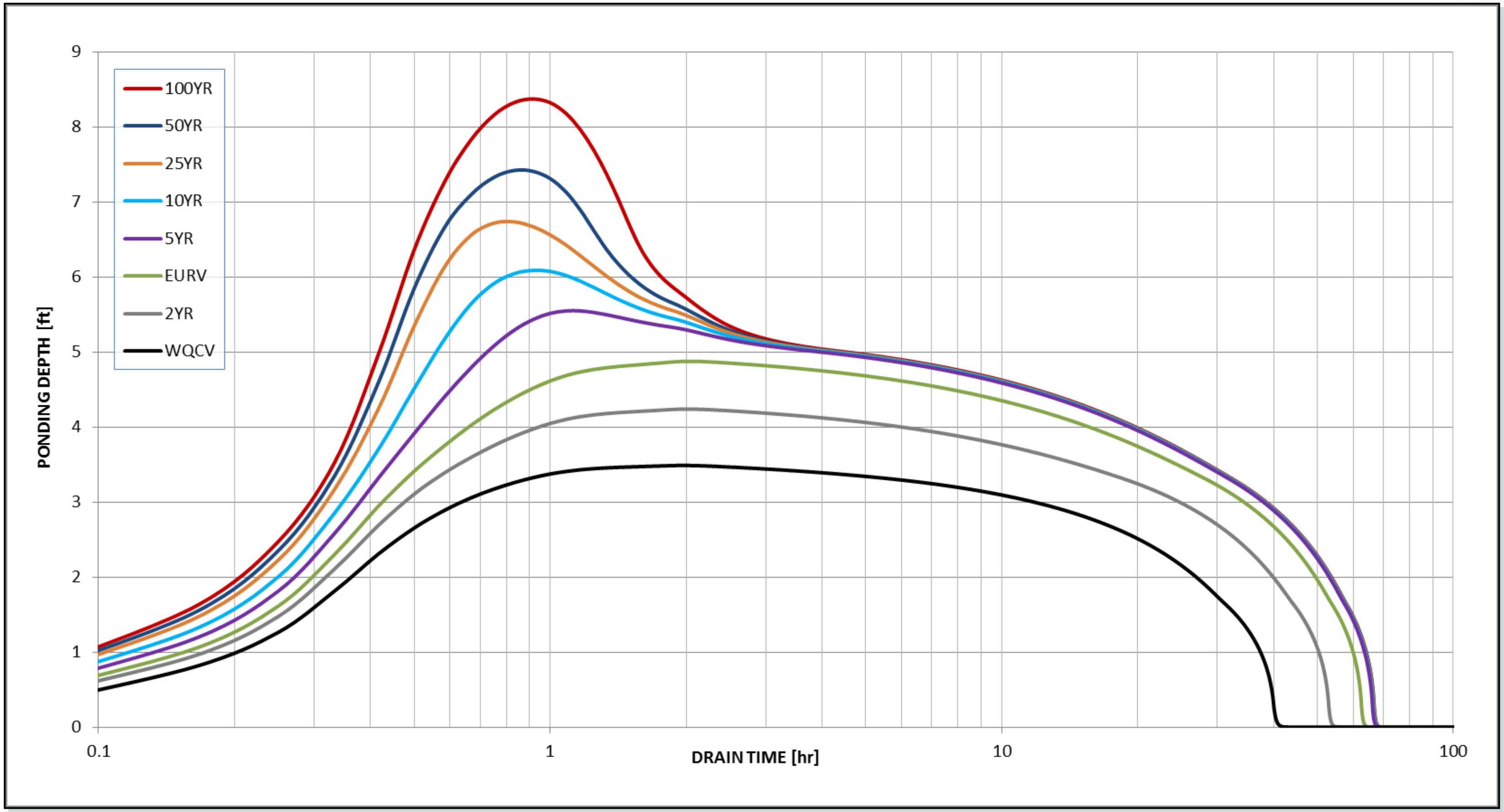

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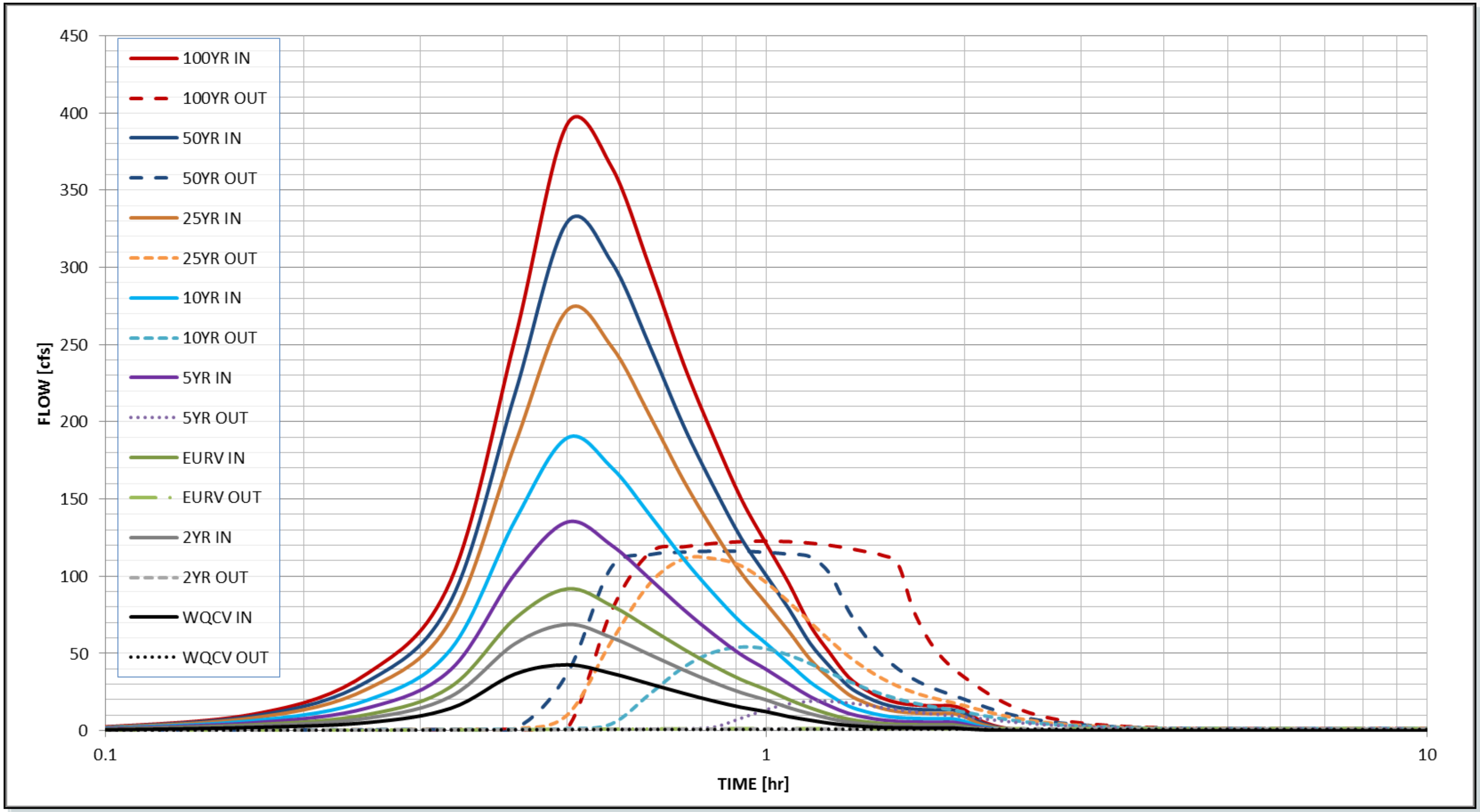

Demonstration of the UD-FSD Workbook