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:

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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.
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
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

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\[ EURV_A = 1.1 \cdot (2.0491 \cdot i - 0.1113) \]
\[ EURV_B = 1.1 \cdot (1.2846 \cdot i - 0.0461) \]
\[ EURV_{CD} = 1.1 \cdot (1.1381 \cdot i - 0.0339) \]

in which, \( EURV_k \) = Excess Urban Runoff Volume in watershed inches \( (K = A, B \text{ or } CD) \)
\( i \) = Imperviousness ratio \( (I/100) \)

![Diagram showing detention volume and imperviousness relationship. The graph illustrates the detention volume (watershed inches) plotted against imperviousness (0% to 100%) for Type A, B, and C or D soils. The graph also includes a line for 100-yr detention volume (includes the Excess Urban Runoff Volume) and a line for Water Quality Capture Volume (WQCV).]
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

\[
\log(Q/(iA)) = \alpha + 81 \log(IMP) + 82 \log(SLP) + 83 \log(SHP)
\]
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).
## Historic & Allowable Runoff for Hydrologic Soil Groups C/D

![Graph showing runoffs for different periods and soil groups](image)

### Return Period

<table>
<thead>
<tr>
<th>Return Period</th>
<th>Hydrologic Soil Group A</th>
<th>Hydrologic Soil Group B</th>
<th>Hydrologic Soil Groups C and D</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-Year</td>
<td>$q_2 = 0$</td>
<td>$q_2 = -0.00128 \times \ln(A) + 0.017$</td>
<td>$q_2 = -0.00144 \times \ln(A) + 0.021$</td>
</tr>
<tr>
<td>5-Year</td>
<td>$q_5 = -0.00124 \times \ln(A) + 0.015$</td>
<td>$q_5 = -0.0221 \times \ln(A) + 0.27$</td>
<td>$q_5 = -0.032 \times \ln(A) + 0.42$</td>
</tr>
<tr>
<td>10-Year</td>
<td>$q_{10} = -0.002 \times \ln(A) + 0.025$</td>
<td>$q_{10} = -0.04 \times \ln(A) + 0.52$</td>
<td>$q_{10} = -0.051 \times \ln(A) + 0.7$</td>
</tr>
<tr>
<td>25-Year</td>
<td>$q_{25} = -0.0236 \times \ln(A) + 0.29$</td>
<td>$q_{25} = -0.08 \times \ln(A) + 1.15$</td>
<td>$q_{25} = -0.088 \times \ln(A) + 1.29$</td>
</tr>
<tr>
<td>50-Year</td>
<td>$q_{50} = -0.047 \times \ln(A) + 0.59$</td>
<td>$q_{50} = -0.103 \times \ln(A) + 1.48$</td>
<td>$q_{50} = -0.11 \times \ln(A) + 1.63$</td>
</tr>
<tr>
<td>100-Year</td>
<td>$q_{100} = -0.073 \times \ln(A) + 0.95$</td>
<td>$q_{100} = -0.124 \times \ln(A) + 1.86$</td>
<td>$q_{100} = -0.132 \times \ln(A) + 2$</td>
</tr>
</tbody>
</table>
100 YEAR EXCESS URBAN RUNOFF VOLUME

LOG(V/PA) = α + β1*LOG(IMP) + β2*LOG(SLP) + β3*LOG(SHP)
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.
\[ EURV_{HSG A} = 1.73 (IMP)^{1.26} \]
\[ EURV_{HSG_B} = 1.33(IMP)^{1.07} \]
\[ EURV_{HSG \ C/D} = 1.15(IMP)^{1.05} \]
EURV_A = 1.73I^{1.26}
EURV_B = 1.33I^{1.07}
EURV_{CD} = 1.15I^{1.05}
Basic Detention Basin Model

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

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

\[ V_{\text{COMPOSITE}} = V_{\text{LOWER}} + V_{\text{UPPER}} \]
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:**

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

Where \( ISV \) is the initial surcharge volume (ft\(^2\)), \( A_{ISV} \) 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:**

\[ L_{floor} = L_{ISV} + \frac{H_{floor}}{S_{TC}} + H_{floor} (S_{main}); \quad W_{floor} = W_{ISV} + \frac{H_{floor}}{R_{L:W}(S_{TC})^2}; \]

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

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:

\[ L_{\text{main}} = L_{\text{floor}} + 2H_{\text{main}}(S_{\text{main}}); \quad W_{\text{main}} = W_{\text{floor}} + 2H_{\text{main}}(S_{\text{main}}); \quad A_{\text{main}} = L_{\text{main}}(W_{\text{main}}); \]

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

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

Total Basin Volume:

\[ V_{\text{total}} = 1SV + V_{\text{floor}} + V_{\text{main}} \]

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

<table>
<thead>
<tr>
<th></th>
<th>Peak Q$_{100}$ from 1-100 Ac Sub-Watershed (cfs)</th>
<th>Peak Q from Ten 100-Acre Watershed (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2-year</td>
</tr>
<tr>
<td>Pre-Development Peak Q</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(I=2%)</td>
<td>139</td>
<td>54</td>
</tr>
<tr>
<td>Developed without Detention (I=45%)</td>
<td>325</td>
<td>491</td>
</tr>
<tr>
<td>Developed with Full Spectrum Detention (I=45%), Outlet Pipe Controls Q$_{100}$</td>
<td>125</td>
<td>11</td>
</tr>
</tbody>
</table>
## Initial Design for Full Spectrum Detention Basins

### User Input: Watershed Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watershed Area</td>
<td>100.00 acres</td>
</tr>
<tr>
<td>Watershed Imperviousness</td>
<td>43.0% percent</td>
</tr>
<tr>
<td>Percentage Hydrologic Soil Group A</td>
<td>0% percent</td>
</tr>
<tr>
<td>Percentage Hydrologic Soil Group B</td>
<td>30% percent</td>
</tr>
<tr>
<td>Percentage Hydrologic Soil Groups C/D</td>
<td>70% percent</td>
</tr>
<tr>
<td>Location for 1-hr Rainfall Depths</td>
<td>UDFCD Default</td>
</tr>
</tbody>
</table>

### User Input: Detention Basin Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of Initial Surcharge Volume</td>
<td>0.33 ft</td>
</tr>
<tr>
<td>Trickle Channel Slope</td>
<td>0.010 ft/ft</td>
</tr>
<tr>
<td>Detention Basin Length-to-Width Ratio</td>
<td>2.00 L:W</td>
</tr>
<tr>
<td>Basin Side Slope (Above Basin Floor)</td>
<td>4.00 H:V</td>
</tr>
<tr>
<td>Available EURV Ponding Depth</td>
<td>5.00 ft (relative to lowest WQ orifice)</td>
</tr>
<tr>
<td>Desired WQCV Drain Time</td>
<td>40 hours</td>
</tr>
</tbody>
</table>
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 with 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
WQ Orifice Plate: Orifice Area per Row = WQ Elliptical Slot

Perforated Plate Examples

4”
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

WQ Orifice Plate: Orifice Area per Row = WQ Elliptical Slot (1.0 x 3/8 inch)
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
WQ Orifice Plate: Orifice Area per Row = WQ Elliptical Slot

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

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

\[ Q_{app} = 0.3015h[f(0)+f(0.603h)] + 0.1415h[f(0.603h)+f(0.886h)] + 0.0570h[f(0.886h)] \]

Orifice Equations

\[ Q = C_d A_r \sqrt{2g(h-C_y)} \]

\[ A_r = H(2W+t)-\frac{\pi HW}{2} \]

\[ C_y = \frac{H}{2} \left( \frac{2W+t}{3} - \frac{2HW}{2} \right) \]

\[ y = \text{vertical depth measured from the weir crest to the elementary flow strip [L]; and} \]

\[ y' = \text{vertical distance measured from the water surface to the elementary flow strip [L].} \]
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

WQ Orifice Plate: Orifice Area per Row = WQ Elliptical Slot

(3/8 inch)
### Initial Design for Full Spectrum Detention Basins

#### 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 Depth

100-Year Outlet Pipe Diameter

100-Year Restrictor Plate Height = 32.0 in
## Initial Design for Full Spectrum Detention Basins

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

<table>
<thead>
<tr>
<th>Design Storm Return Period</th>
<th>WQCV</th>
<th>2 Year</th>
<th>EURV</th>
<th>5 Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-Hour Rainfall Depth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculated Runoff Volume</td>
<td>1.926</td>
<td>3.092</td>
<td>4.114</td>
<td>6.041</td>
</tr>
<tr>
<td>OPTIONAL Override Runoff Volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inflow Hydrograph Volume</td>
<td>1.926</td>
<td>3.091</td>
<td>4.113</td>
<td>6.039</td>
</tr>
<tr>
<td>Historic Peak Flow Rate Per Acre (q)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Historic Peak Q</td>
<td>0.0</td>
<td>1.3</td>
<td>7.1</td>
<td>33.0</td>
</tr>
<tr>
<td>Peak Inflow Q</td>
<td>42.6</td>
<td>68.8</td>
<td>91.8</td>
<td>135.1</td>
</tr>
<tr>
<td>Peak Outflow Q</td>
<td>0.9</td>
<td>1.2</td>
<td>1.3</td>
<td>19.0</td>
</tr>
<tr>
<td>Ratio Peak Outflow to Historic Q</td>
<td></td>
<td></td>
<td></td>
<td>0.6</td>
</tr>
<tr>
<td>Structure Controlling Flow</td>
<td>WQ Plate</td>
<td>WQ Plate</td>
<td>WQ Plate</td>
<td>Grate</td>
</tr>
<tr>
<td>Max Velocity through Grate</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.3</td>
</tr>
<tr>
<td>Time to Drain Detention Basin</td>
<td>40</td>
<td>53</td>
<td>63</td>
<td>66</td>
</tr>
<tr>
<td>Maximum Ponding Depth</td>
<td>3.49</td>
<td>4.24</td>
<td>4.88</td>
<td>5.55</td>
</tr>
<tr>
<td>Maximum Volume Stored</td>
<td>1.798</td>
<td>2.925</td>
<td>3.922</td>
<td>5.021</td>
</tr>
</tbody>
</table>
## Initial Design for Full Spectrum Detention Basins

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

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

![Graph showing AREA (ft²), VOLUME (ft³), and OUTFLOW (cfs) vs PONDING DEPTH (ft).]
Initial Design for Full Spectrum Detention Basins

![Graph showing ponding depth vs. drain time for different return periods.](image-url)
Initial Design for Full Spectrum Detention Basins
Demonstration of the UD-FSD Workbook