Green Infrastructure Right-of-Way Inlet Type Selection: Hydraulic and Siting Factors to Consider to Optimize Design
How does a green infrastructure system capture water in urban areas?

Capture Water Through Green Infrastructure Inlets
Types of Green Infrastructure Inlets
Four Types of Inlets

Roadway Drainage

a. Grate
b. Curb-opening Inlet
c. Combination Inlet
d. Slotted Drain Inlet

Source: FHWA Urban Drainage Design Manual

Source: Hazen
Siting and Sizing Factors
Green Infrastructure
Inlet Selection and Placement

- Hydraulic Considerations
- Site Constraints
- Public Implications
How can we optimize the capture efficiency of a green infrastructure inlet?

Hydraulic Considerations

- Inlet Geometry
- Storm Intensity and Duration
- Drainage Area
- Roadway Design
- Gutter Characteristics
- Inlet Aprons
- Debris Clogging
- Conveyance to Green Infrastructure
Hydraulic Considerations for a Grate Inlet
Site Constraints and Other Factors

- Presence and type of curbing
- Proximity to buildings, utilities, streetscape, trees, ADA ramps, etc.
- Conveyance to green infrastructure system
- Pretreatment
- Maintenance and access
- Constructability
- Allowable spread
- Pedestrian and driver impacts
- Cost
### Site Constraints and Other Factors

**Green Infrastructure Inlet Site Placement**

<table>
<thead>
<tr>
<th>SAG</th>
<th>VS</th>
<th>CONTINUOUS GRADE</th>
</tr>
</thead>
</table>

- **Low point inlets** – “online” GI and capacity risk/consequence
- **Continuous grade inlets** not as efficient by definition (e.g. splash-over)
- Clogging implications are different (e.g. curb opening litter more easily dislodged in sag)
Green Infrastructure Inlet Site Placement in Urban Environments
Controllable Factors

Hydraulic Considerations
- Inlet Type Selection
- Inlet Size
- Presence of Inlet Apron
- Presence of Gutter

Siting and Other Constraints
- Inlet Type Selection
- Proximity to GI System
- Pretreatment
- Public Implications
Green Infrastructure Inlet Analysis
Design Factors

- Select number of factors and some implications
  - Drainage area
  - Longitudinal slope (good direct surrogate for velocity, splash-over, bypass)

\[
V = \left(\frac{K_u}{n}\right) S_L^{0.5} S_x^{0.67} T^{0.67}
\]

\[
(d/D) = K_u \left[\left(\frac{Q_n}{Q}\right) / \left(D^{2.67} S_L^{0.5}\right)\right]^{0.488}
\]

\[
Q_i = C_a A_g \left\{2g \left[d_i - \frac{(h/2)}{2g}\right]\right\}^{0.5}
\]

\[
Z_1 + y_1 + \frac{V_1^2}{2g} = Z_2 + y_2 + \frac{V_2^2}{2g} + h_L
\]

\[
E_a = \frac{1}{\left(1 + \frac{S_a}{S_x}\right)^{0.67}}
\]

\[
Q_N = Q - Q_a
\]

\[
Q = Q_a / (1 - E_a)
\]
Assumptions for both:
- Drainage Area = 5,000 SF
- 1-year, 10 min storm
- Road cross slope = 2%
- Gutter cross slope = 4%
- Gutter width = 2 feet

GI Takeaways:
- Require less throat length for flatter streets, is not as large an effect as spread across range of slopes—may need to add duplicate inlets to capture 1-year storm intensity, added costs for GI piping configuration and excavation
Grate Inlet vs. Curb Opening Inlet – Capture

GI Implications
- Grate inlets theoretically perform well over much larger range of drainage area
- Assuming heavy clogging, can reduce drastically, may need to consider adding additional inlets

Assumptions
- 1-year, 15 min storm
- Road cross slope = 2%
- Gutter cross slope = 4.2%
- Gutter width = 2.5 feet
- Curb inlet length = 4.5 feet
- Grate length = 4 feet
- Grate type = CDOT/Denver 13 Valley Grate

But where is the design storm in this efficiency?
Curb Opening: Depressed Inlet Throat or At-Grade?

**GI Implications**
- GI system and pipe utilization may increase with a small depression in the throat
- More capture at higher contributing areas can stretch GI dollars farther (but don't forget spread!)

**Assumptions**
- 1-year, 15 min storm
- Road cross slope = 2%
- Gutter cross slope = 4.2%
- Gutter width = 2.5 feet
- Curb inlet length = 4.5 feet
- Grate length = 4 feet
- Grate type = CDOT/Denver 13 Valley Grate

At largest contributing area modeled, throat can increase inlet capacity 14% and 25%

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**Graph Description:**
- Y-axis: Capture Efficiency (%)
- X-axis: Contributing Impervious Area (SF)
- Lines for:
  - No Depression
  - 1" Depression
  - 2" Depression

**Legend:**
- No Depression
- 1" Depression
- 2" Depression

**Inlet throat depression**
Annual Runoff Analysis
Storm and Sanitary Analysis

Simple Inlet, Gutter Bypass, and Green Infrastructure Setup

Alexandria, VA
2014 Rainfall = 37.41 in.
Storm and Sanitary Analysis

Cumulative Capture vs Bypass

Graph showing cumulative annual volume (cubic foot) from January 2014 to December 2014, with two lines representing Bypass and GI Inflow.
Inlet Types – Annual Performance

Frontal vs side flow of grate?
GI Capture and Curb Opening Length

<table>
<thead>
<tr>
<th>Annual Volume (cubic feet)</th>
<th>0 in. Depress.</th>
<th>1 in. Depress.</th>
<th>2 in. Depress.</th>
<th>0 in. Depress.</th>
<th>1 in. Depress.</th>
<th>2 in. Depress.</th>
</tr>
</thead>
<tbody>
<tr>
<td>L = 36 in.</td>
<td>38.1%</td>
<td>51.6%</td>
<td>61.7%</td>
<td>67.8%</td>
<td>85.7%</td>
<td>95.3%</td>
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<tr>
<td>L = 72 in.</td>
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BMP Inflow  Bypass
Capture Implications

- Increased depression is better for annual capture, balance with traffic and bike safety
- Grates are better at capture in most apples-to-apples scenarios
  - Lowers hydraulic grade line at inlet = more excavation or reduces surface filtration opportunity
  - Cost vs. curb cut / curb opening

Portland, OR. Photo by: A. Anderson 2014
Capture Implications
Summary of Cumulative Capture Implications

• Tradeoff between what’s good in perfect world of placing inlets vs reality on the ground—what is there room for
• Design storm vs annual capture
• Retrofits of inlets require precision to translate design assumptions to reality
Maintenance and Green Infrastructure

• An improperly functioning inlet is an under-utilized green infrastructure system

• Potential maintenance triggers by inlet type:
  • Curb Opening
    • Structural cave-in of curb opening
    • Sediment build-up in depressed apron
    • Large debris build-up in throat
  • Grate Inlet
    • High leaf, organic, and litter clogging on grate can create flooding nuisance
  • Combination Inlet
    • Provides multi-modal flow diversion if one method is ineffective (opening vs. grate)
<table>
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<tr>
<th>Implications of Improper Selection and Placement</th>
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<tbody>
<tr>
<td>Idle Green Infrastructure System</td>
</tr>
<tr>
<td>High Sediment Loading in Green Infrastructure System</td>
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<tr>
<td>Localized Ponding and Spread</td>
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<tr>
<td>Driver and Pedestrian Hazards</td>
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<tr>
<td>Excess Debris and Supplemental Maintenance</td>
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<tr>
<td>Elevated Costs</td>
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Questions?

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