Treatment of Runoff with Roadside Drainage Ditches


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ST. ANTHONY FALLS LABORATORY

University of Minnesota
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Problem Statement

Stormwater Runoff: non-point source of pollution

Water Quality

Runoff from highways:
TSS, Nutrients, Metals, Organic Compounds

Water Quantity

Liu et al., 2014
Non-Source Pollution: Permits

- NSPDES
- MS4
  - Municipalities
  - Public Entities
    - Universities
    - Counties
    - DOT
Minimal Impact Design Standards

Next Generation of Stormwater Management (MPCA Stormwater Manual)

Linear projects that create 1 acre or greater of new and/or fully reconstructed impervious surfaces, shall capture and retain the larger of the following:

- 0.55 inches of runoff from the new and fully reconstructed impervious surfaces
- 1.1 inches of runoff from the net increase in impervious area

All projects shall first attempt to meet the volume reduction Performance Goal on site.
Green Infrastructure “reduces and treats stormwater at its source” US. EPA

Roadside Drainage Ditches = Filter Strips / Swales

Twincities.com
Roadside Drainage Ditches / Swales

Quantification of Infiltration performance
Roadside Drainage Ditches / Swales

Project Steps:

1. Field tests
2. Model
3. Simplified Model = Calculator
Field Experiments
Field Experiments

- **Simulated Runoff Tests**
  - 4 Highways in TC Metro Area
    - 2 sites/Hwy
  - 3 intensities
    - 1, 2, 10-year storms
  - 3 Seasons
    - Fall, Spring, and Summer
Field Experiments

Field Classified-Soil Texture (552 samples across the State)

- Clay 7%
- Clay loam 7%
- Sandy clay loam 19%
- Sandy clay 15%
- Sandy loam 20%
- Silt loam 5%
- Silty clay 7%
- Loamy sand 11%
- Sandy clay loam 7%
- Clay loam 5%
- Loam 3%
- Sand 1%

Soil Types
- Loam
- Loamy sand
- Sandy loam
- Sandy clay loam

- 53% soils found in road embankments
Field Experiments
Field Experiments
### Field Experiments

#### Saturated Hydraulic Conductivity ($K_{sat}$) measurements

<table>
<thead>
<tr>
<th>Highway</th>
<th>$K_{sat}$ (cm/h)</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hwy 51</td>
<td>3.54 (1.44)*</td>
<td></td>
</tr>
<tr>
<td>Hwy 77</td>
<td>5.74 (0.94)*</td>
<td></td>
</tr>
<tr>
<td>Hwy 47</td>
<td>3.47 (1.29)*</td>
<td></td>
</tr>
<tr>
<td>Hwy 13</td>
<td>4.14 (1.87)*</td>
<td></td>
</tr>
</tbody>
</table>
Field Experiments

Results

Fraction of Wetted Area = 0.00225 \times \text{Intensity} + 0.581
R^2 = 0.999
Field Experiments

Results

![Bar chart showing infiltration results for different conditions](chart.png)

- **Fall Medium Flux (T1)**: 90% (Fall 2-year)
- **Spring Medium Flux (T1)**: 75% (Spring 2-year)
- **Low Flux (T2)**: 70% (Spring 1-year)
- **High Flux (T3)**: 50% (Spring 10-year)

MPD tests
Infiltration-Overland Flow Model
Input Parameters

Set Initial and Boundary Conditions

Infiltration Submodule
Output: Infiltration Rate (i)
Green-Ampt Mein-Larson

Overland Flow Submodule
Output: Water Depth (h)
Kinematic Wave Approximation

Is h > Depression storage (ds)

Qout = 0
No
Yes
Calculate Qout
Manning’s equation

Next Time step

Next Cell

Last Time step and Last Cell

Is Cr < 1

Change Number of Time Steps (T)
T = T * Cr
dt = duration/T

No
Yes
Runoff - Qout (last cell)
Infiltration (all cells over time)

End
Infiltration-Overland Flow Model

Reality

Concentrated Flow (fw)

Non Concentrated Flow (1-fw)

Model

Side Slope Runoff

Road Runoff

Rainfall
Infiltration-Overland Flow Model
Infiltration-Overland Flow Model

Input Parameters

Side Slope Module

Concentrated Flow
Road Runoff and Rainfall over wetted fraction (fw)
Output: Qslope_1, Infiltration_1

Non-Concentrated Flow
Rainfall over non-concentrated fraction
Output: Qslope_2, Infiltration_2

Q_side_slope = Qslope_1 + Qslope_2
Infiltration_side_slope = Infiltration_1 + Infiltration_2

Channel Module

Results
Inflow = Inflow_slope_1 + Inflow_slope_2 + Inflow_Channel
Infiltration = Infiltration_slope + Infiltration_Channel
Runoff = Runoff_Channel
%Infiltration = 1 - Runoff / Inflow
Infiltration-Overland Flow Model
Validation

K\textsubscript{sat} input: estimated in the field

N=12
RMSE = 6%
Normalized MSE = 12%

\textbf{Infiltration Measured vs Predicted}

\begin{itemize}
\item 1-year & 10 year events
\item Linear (1:1)
\end{itemize}
Infiltration-Overland Flow Model Validation

![Graph showing infiltration and overland flow model validation]
Infiltration-Overland Flow Model

Matlab Model

Inputs:

- Rainfall intensity ($i$)
- Duration of storm event ($t$)
- Length of side slope ($L$)
- Soil suction head ($\psi$)
- Soil water deficit ($\Delta\theta$)
- Saturated Hydraulic Conductivity ($K_s$)
- Width of swale and channel ($w$) ($B$)
- Fraction wetted ($f_w$)
- Side slope ($S$)
- Manning’s $n$ ($n$)
- Depression storage ($ds$)
Simplification of the Model

= Swale Calculator
Simplification of the Model

Sensitivity and Uncertainty Analyses

Percentage of Sensitivity * Uncertainty

- Ksat
- $\psi$
- $\Delta \theta$
- fw
- B
- n
- ds
- S
Swale Calculator

1- Saturated Hydraulic Conductivity ($K_{sat}$)

3- $K_{sat} + W_{swale} / W_{road} = \%\, Infiltration$

Ahmed et al. (2015)

2- Width of the road and side slope

4- Location (Percentile Rainfall Volume)
Swale Calculator

Example:
Ksat = 2 cm/h
0.79 in/h

Wroad = 10 m
33 ft

Wswale = 4 m
13 ft
Download Calculator

- [http://stormwater.safl.umn.edu](http://stormwater.safl.umn.edu)
- Resources/Roadside Swale Calculator
- Publications/Reports
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• St. Anthony Falls Laboratory (SAFL)
  – Andy Erickson
  ➢ http://stormwater.safl.umn.edu
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Stormwater Management Practice

SMPs are closer than they appear

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