Filtration and Sorption + Settling: BMP Process Modeling for Water Quantity and Quality

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FILTRATION BMPS

- Bioretention Cells
- Sand Filters
- Infiltration Trench
- Porous Pavement
- Engineered Device
- Vegetative Filter Strips
- Bioswales
- Enhanced Bioswales
Example BMPs
Above Ground and Below Ground Processes

Surface Impoundment stores and detain water to enhance particle settling and infiltration.

Subsurface component allows infiltration; filters fine sediment, dissolved solids, and bacteria using soil matrix; and decreases runoff volume.
Above Ground Component: Hydraulics

- Routes storm through storage space
- Depends on storage volume and outlet configuration
- Standard continuity routing
  - Many different outlet configurations
Above Ground Component: Hydraulics

\[
\frac{dV}{dt} = q_i - q_o
\]
Above Ground Component: Sediment Trapping

Particles settle as primary and aggregated particles.

Aggregated particles settle as groups of particles held together by clay and OM:
- Large Agg - ft/sec
- Small Agg - ft/sec - ft/hr

Primary particles settle individually:
- Sand - ft/sec
- Silt - ft/hr
- Clay - ft/day - ft/month
Above Ground Component: Sediment Trapping (Cont’d)

Settling Velocity

\[ V_{si} \quad i = 1 \text{ to } 5 \]

\[ TE_i = \left[ 1 - \frac{1}{\beta} \left( \frac{V_{s,i}}{V_c} \right)^\beta \right] \]

\[ V_c = \frac{q_t}{A_t} \]

EPA Model

Many limitations
Replacing EPA Model Reactor Based Model No. 1
Ward DEPOSITS Plug Flow Model

Step 1: Divide hydrographs into plugs

- Inflow hydrograph
- Detention time for plug $J = T_J$
- Plug volume for plug $J$
- Previously stored flow
- Outflow hydrograph

Flow Rate (cms)

<table>
<thead>
<tr>
<th>Time (hrs)</th>
<th>0</th>
<th>4</th>
<th>8</th>
<th>12</th>
<th>16</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Rate</td>
<td>0</td>
<td>4</td>
<td>8</td>
<td>12</td>
<td>16</td>
<td>20</td>
</tr>
</tbody>
</table>
Step 2: Divide each into multiple layers

Step 3: Calculate the sediment removed from each layer

\[ C = \begin{vmatrix}
W_{F,1}C_1 + W_{F,2}C_2 \\
+ W_{F,3}C_3 + W_{F,4}C_4
\end{vmatrix} \]
Reactors Based Models No 2
Wilson BASIN Model

- Divide into horizontally mixed CSTRS
- Vertical turbulent diffusion
## Settling – Some More Background

<table>
<thead>
<tr>
<th>Particle Class</th>
<th>Size</th>
<th>mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary clay</td>
<td>Cl</td>
<td>0.002</td>
</tr>
<tr>
<td>Primary silt</td>
<td>Si</td>
<td>0.010</td>
</tr>
<tr>
<td>Primary sand</td>
<td>Sa</td>
<td>0.200</td>
</tr>
<tr>
<td>Small Aggregates</td>
<td>Sg</td>
<td>0.03-0.10</td>
</tr>
<tr>
<td>Large Aggregates</td>
<td>Lg</td>
<td>0.30+</td>
</tr>
</tbody>
</table>
Above Ground Component: Nutrient and Bacteria Trapping

Nutrients and bacteria sorbed to primary clay particles that reach bottom trapped

Nutrients & bacteria sorbed to clay particles in aggregates that reach bottom trapped

Bacteria sorbed to primary silt particles that reach bottom trapped

Bacteria loosely sorbed to primary sand particles that reach bottom ignored

IDEAL Workshop 2/5/2007
Sorption/Desorption Mechanics

$C_s = \text{Conc on Clay (mg/g)}$

$C_\ell = \text{Conc in Liquid Phase (mg/\ell)}$

Linear isotherm for soil

Linear isotherm for fly ash
Partitioning Chemicals for Calculating Sorption

\[
EMC = EMC - \text{Particulates} + \text{Sorbed}
\]

\[
(Sorbed) = (Dissolved) \times (Isotherm \ K) \times (Mass \ Clay)
\]
Biological Processes

Pathogen Trapping (Non Biological)

- Partitioned into planktonic (floaters) and sorbed using EMC and pathogen isotherm.
- Pathogens sorbed onto silt as well as clay. Sorption onto silt weaker than clay.
- Trapping based on trapping of pathogens sorbed to primary clays, primary silts and silt and clays in aggregates. Procedure is the same as for chemicals.
Biological Processes: Losses Due to Mortality

- Natural mortality and predation losses
  - Dependent upon temperature
  - Location of sorbed pathogens
- Mortality losses due to exposure to sunlight based on predicted solar radiation
  - Attenuation of radiation into ponds
  - Attenuation due to turbidity (TSS)
- Mortality losses due to desiccation (being developed for loading calculations)
Dilution With Stored Water

The solution to pollution is dilution

- Water stored in a BMP between storms, is clarified by settling.
- Can grow algae as well
- Stormflow displaces some of stored water and total runoff is diluted downstream.
- Outflow concentration for permanent pool flow assumed to be equal to concentration at start of storm
- Use a priming storm to determine this concentration
Subsurface Processes

- Infiltration including preferential flow
- Sorption/desorption
- Filtration
Subsurface Processes

- Green & Ampt for Infiltration
- Preferential flow calculated separately
- Sorption calculated by isotherm using a washtub concept
- Modifications for additives such as flyash
- Filtration
Filtration: Mechanical and Physiochemical Impacts

- Some mechanical trapping by particles too large to go through pores (large sand particles)
- Other particles can go through pores, but are trapped
  - Trapped by physiochemical processes
  - Flows typically turbulent free or low turbulence
Filtration

• Trapping based on trajectories through media
  – Direct hit
  – Get close enough to count
  – Wander in due to Brownian motion
  – All of these are modeled.

• Only a small fraction of hits stick.
• Probability of sticking is low due to week electrochemical attraction.
Filtration

- High trapping results from large number of sand particles in the path through the media
- Overcomes the low probability of sticking.
What Filtration Can Trap

- Most sand, silt, large and small aggregates.
- Most clays if flow through velocity is small enough and filter is thick enough.
- Particulate chemicals and sorbed chemicals on the clays.
- Large fraction of the pathogens.
- Can be an attractive nuisance for wildlife.
LID BMPs
Dry Bioswale
Dry Bioswale (cont’d)
Dry Bioswale Flow Hydraulics

- Modeling Approach
  - Calculate flow velocity and rate using ARS/NRCS grass waterway equations from Ag Handbook 667
  - Determine an average depth for sediment transport calculations
Dry Bioswale
Flow Hydraulics

- Key issue in calculating flow properties is determining the Manning’s roughness
- Manning’s roughness is highly variable, depending on the product of velocity times hydraulic radius VR
Dry Bioswale
Flow Hydraulics

- Manning’s roughness is key issue
- Highly variable function of VR

Figure 1. Comparison of Equation 3 and data.
Dry Bioswale User Inputs

- Channel Properties
  - Trapezoidal Section
    - Bottom width
    - Size slopes
    - Maximum depth
  - Parabolic Section
    - Maximum depth
    - Top width
  - Triangular Section
    - Top width
    - Max depth
  - Channel Slope
  - Channel Length
  - Percent Peak Flow for Routing
Dry Bioswale User Inputs – Cont’d

- Soils Information for Infiltration
  - Soil Texture
  - Degree of saturation

- Vegetative Properties
  - Bioswale land use
  - Type vegetation and density (stems/sq ft)
  - Frequency of mowing

- Characteristics selected by IDEAL based on type vegetation
  - Grass height mowed and unmowed
  - Calibrated Manning’s roughness
LID BMPs
Enhanced Bioswale

Infiltration and filtration of suspended particles
Percolation and sorption of chemicals onto soil matrix
Optional perforated underdrain for heavy soils
Filter Strip BMPs

VFS and Buffer Strips
VFS Project Southeast
Kentucky

200 by 100 ft – 20% Slope

Fig. 7—Outflow concentration vs. time for field test 1.
Vegetative Filter Strip

- Can be put anywhere in the treatment train
- Typically used downstream of an impervious area
- Has a diffuse source connector
FLOW HYDRAULICS IN VFS

Inflow Rate

Flow Velocity

Infiltration Rate

Flow Depth

Outflow Rate

The important hydraulic parameters...
Hydraulic Calculations for VFS

Velocity - Manning’s Equation

Use same relationships as Bioswale to determine velocity and depth of flow
Modeling Infiltration Rate

Constant rate, or
Green and Ampt Equation
Hydraulic Inputs for VFS

- Type vegetation
- Roughness (Manning’s n)
- Density $S_s$ (spacing of vegetated media)
- Slope $S$ (ft/ft)
- Height of vegetation selected by IDEAL based on type of vegetation
- Frequency of mowing
- VFS land use (lawn or pasture)
- Infiltration rate
  - Average value (saturated hydraulic conductivity for constant rate (iph))
  - Degree of saturation and soil texture for variable rate Green and Ampt equation
  - Unsaturated flow properties selected by IDEAL based on soil texture
Bioretention Cell BMPs

BRC, Rain Gardens, Planter Boxes
Bioretention Cell
Rain Garden
Bioretention Cells
How They Work

- Above ground portion
  - Shallow highly pervious detention basin
  - Effective for small storms
  - Not effective for large storms
  - Modeled the same as ponds with bottom infiltration
Bioretention Cells
How They Work

- Infiltration
  - Decreases runoff volume
  - Filters sediment, metals, and nutrients from flow
  - Not highly effective in removing nitrates
  - Recovers infiltration capacity between storms, dependent on type vegetation present
  - Modeled with Green – Ampt equation
Bioretention Cells
Hydraulics

- Hydraulic routing same as pond with infiltration
- Infiltration uses multiple layers
IDEAL LID BMPs
Bioretention Cell Infiltration

- Green and Ampt Equation
  - Based on Darcy’s Law

\[ f = K \frac{\Delta H}{\Delta Z} = K \frac{\Delta H}{L} \]

\[ \Delta H = d_p + L + \Psi \]

\[ f = K \left[ 1 + \frac{\Delta \theta (d_p + \Psi)}{F} \right] = \frac{dF}{dt} \]

\[ F = K t + \Delta \theta (d_p + \Psi) \ln \left[ 1 + \frac{\Delta \theta (d_p + \Psi)}{F} \right] \]
IDEAL LID BMPs
Bioretention Cells User Inputs

- Above Ground Impoundment
  - Area
  - Diameter of principal outlet riser (drop inlet) and barrel
  - Distance from top of riser to bottom of barrel outlet
  - Crest of overflow EMS (top of impoundment)
  - Length of overflow crest
  - Barrel coefficients (entrance loss, bend loss, Manning’s n)
  - Max permissible velocity in pipe
IDEAL LID BMPs
Bioretention Cells User Inputs

- Below Ground Storage
  - For up to four layers
    - Media type
    - Media name
    - Initial water content
    - Layer depth
  - Underdrain inputs
    - Number and radius of underdrains
    - Depth to impervious layer
Sand Filter BMPs

Stormwater Sand Filters
BMPs: Stormwater Sand Filters

- Porous Rock Fill Barrier
- Sedimentation Forebay
- Sand Filter
BMPs: Stormwater Sand Filters
BMPs: Stormwater Sand Filters

Sand Filter

Inlet for Stormwater Drain
BMPs: Stormwater
Sand Filters - Flow Divider

Top of WQV
BMPs: Stormwater Sand Filter for a Building
Stormwater Sand Filter BMP Model - Hydraulics

Factors impacting flow through sand

- Head on filter
- Characteristic size of media
- Porosity
- Compaction and ripening

Empirical equations: Carman-Kozney Eq

\[ V_o = \left[ \frac{g}{5v} \frac{\varepsilon^3}{(1 - \varepsilon)^2 S_o^2} \right] \frac{\Delta h}{L} \]

\[ S_o = \frac{7.5}{d_c} \]

For clean sand
Empirical equations: Darcy’s Law

\[ V_o = K \frac{\Delta h}{L} \]

\[ K = \text{hydraulic conductivity} \geq 3.5 \text{ ft/day} \]

For sand with some ripening