Assessment of agricultural best management practices using mathematical models: a review

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Contents

1. Background
2. Watershed models
3. BMP models
4. Decision Support System
5. Implication
Background: What is BMPs

**Point BMP**: Practices that capture upstream drainage at a specific location and use a combination of detention, infiltration, evaporation, settling, and transformation to manage flow and remove pollutants.

**Linear BMP**: Areas adjacent to the stream channels that provide filtration of runoff, nutrient updates, and ancillary benefits of shading, habitat, and aesthetic value.

**Area-based Practices**: Land-based practices that affect larger area management, land cover and pollutant Inputs (e.g., fertilizer, pet waste)
Biotention at Xikeng Reservoir, Shenzhen, China
A theoretical construct system to represent those geological-, hydrological-, and ecological processes in watersheds.

Incorporating prior observations drawn from field and laboratory data.

Background: What is a model?
Background: Model Categories

• Landscape models
  – Runoff of water and materials on and through the land surface

• Watershed models
  – Combination of landscape and receiving water models

• Site-scale models (BMP models)
  – Detailed representation of local processes

• Decision Support System (DSS)
  – Incorporation of GIS, watershed model and BMP model
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## Explicit vs. Lumped Treatment

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<th>Model Processes</th>
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# A summary of reported literature

## Table 2: Comparison of the assessment ability of watershed models based on reported literatures

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## Summary of Watershed Models

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<tr>
<th>Models</th>
<th>Temporal resolution</th>
<th>Spatial representation</th>
<th>Overland flow routing</th>
<th>Overland sediment routing</th>
<th>Channel processes</th>
<th>Developer</th>
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<tr>
<td>SWAT</td>
<td>Continuous, daily or sub-daily time steps</td>
<td>Sub-basins or further hydrologic response units defined by soil and land use/land cover</td>
<td>CN method for infiltration and peak flow rate by modified Rational formula</td>
<td>MUSLE characterized by runoff volume, peak flow rate, and USLE factors</td>
<td>Channel degradation and sediment deposition with CH_EROD, CH_COV, CH_N2 and channel geometry to represent BMPs</td>
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<td>AGNPS</td>
<td>Storm-event, one storm duration as a time step</td>
<td>Cells of equal size with channels included</td>
<td>CN method for infiltration, and flow peak using a similar method with SWAT</td>
<td>USLE for soil erosion and sediment routing through cells with USLE factors to be concerned with</td>
<td>Included in overland cells</td>
<td>USDA</td>
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<td>AnnAGNPS</td>
<td>Continuous, daily or sub-daily steps</td>
<td>Cells with homogeneous soil and land use</td>
<td>CN method for infiltration and SCS TR-55 method for peak flow</td>
<td>RUSLE to generate soil erosion daily or user-defined runoff event</td>
<td>Channel degradation and sediment deposition with Modified Einstein equation and Dagnold equation</td>
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<td>HSPF</td>
<td>Continuous, variable constant steps (from 1 minute up to 1 day)</td>
<td>Pervious and impervious land areas, stream</td>
<td>Philip’s equation for infiltration</td>
<td>Rainfall splash and wash-off of detached sediment calculated by an experimental non-linear equation</td>
<td>Non-cohesive and cohesive sediment transport</td>
<td>USGS, USEPA</td>
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How SWAT represent various BMPs

- **WDM: Watershed Data Management Files (Time Series Store, TSS Files)**

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## Two typical BMP models

### Table 2 Summary of BMP models and their characteristics

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<thead>
<tr>
<th>Model</th>
<th>Modules</th>
<th>Processes/ Mechanisms</th>
<th>Water Quality Constituents</th>
<th>Developer</th>
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<td>Infiltration, Evapotranspiration, Surface and subsurface flow routing, Nutrients cycling (C, N, P), Sediment transport</td>
<td>Sediment, Nutrients (C, N, P)</td>
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### BMP models: Point BMPs

<table>
<thead>
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<th>BMPs</th>
<th>Present Approach</th>
<th>Optional Future Approaches</th>
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| Bioretention | • Holtan-Lopez equation  
              • Constant evapotranspiration (ET) rate  
              • Stage-outflow storage routing using weir and/or orifice equations  
              • Completely mixed pollutant routing  
              • 1st order decay  
              • Under drain percent reduction (user defined) | • Green-Ampt infiltration  
              • Calculate potential ET and actual ET  
              • Continuously stirred tank reactor (CSTR) in series pollutant routing  
              • Plug flow pollutant routing  
              • Kadlec and Knight’s (1996) 1st order kinetic method  
              • Sedimentation  
              • Physically based substrate filtration and sorption |
| Detention pond | • Holtan-Lopez equation  
              • Constant ET rate  
              • Stage-outflow storage routing using weir and/or orifice equations  
              • Completely mixed pollutant routing  
              • 1st order decay | • Green-Ampt infiltration  
              • Calculate potential ET and actual ET  
              • CSTR in series pollutant routing  
              • Plug flow pollutant routing  
              • Kadlec and Knight’s 1st order kinetic method  
              • Sedimentation |
# BMP models: Point BMPs

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<th>Optional Future Approaches</th>
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<td>• Green-Ampt infiltration&lt;br&gt;• Calculate potential ET and actual ET&lt;br&gt;• Pollutant routing CSTR in series or plug flow&lt;br&gt;• Kadlec and Knight’s (1996) 1st order kinetic method&lt;br&gt;• Sedimentation</td>
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<td>Infiltration trench</td>
<td>• Holtan-Lopez equation&lt;br&gt;• Constant ET rate&lt;br&gt;• Stage-outflow storage routing using weir and/or orifice equations&lt;br&gt;• Completely mixed pollutant routing&lt;br&gt;• 1st order decay</td>
<td>• Green-Ampt infiltration&lt;br&gt;• Calculate potential ET and actual ET&lt;br&gt;• Pollutant routing CSTR in series or plug flow&lt;br&gt;• Kadlec and Knight’s (1996) 1st order kinetic method&lt;br&gt;• Sedimentation&lt;br&gt;• Physically based substrate filtration and sorption</td>
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### BMP models: Linear BMPs

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<td><strong>Linear BMPs:</strong> Areas adjacent to the stream channels that provide filtration of runoff, nutrient uptakes, and ancillary benefits of shading, habitat, and aesthetic value</td>
<td>• Pollutant trap efficiency as a function of strip width (flow length)</td>
<td>• Nonlinear reservoir overland flow routing</td>
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<td>Buffer Strip/Riparian Buffer</td>
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<td>• Kinematic wave overland flow routing</td>
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<td>• Process-based sediment interception simulation method</td>
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<td>• Process-based nutrient/pollutant removal simulation method</td>
</tr>
</tbody>
</table>
# BMP models: Area-based BMPs

<table>
<thead>
<tr>
<th>BMPs</th>
<th>Present Approach</th>
<th>Optional Future Approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Area BMPs:</strong> Land-based practices that affect impervious area management, land cover, and pollutant inputs (e.g., fertilizer, pet waste)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Street Sweeping</td>
<td>• Street sweeping pollutant removal effectiveness (SWMM)</td>
<td>• Additional controls on type and frequency of sweeping</td>
</tr>
<tr>
<td>Impervious area reduction</td>
<td>• Pervious/impervious areas (SWMM)</td>
<td>• Impervious area to pervious area land routing</td>
</tr>
<tr>
<td>Land management</td>
<td>• Pollutant build-up/wash-off rates (SWMM)</td>
<td>• Update to Universal Soil Loss Equation (USLE), adjustment of parameters</td>
</tr>
<tr>
<td></td>
<td>• Infiltration rate (SWMM)</td>
<td>• Process-based simulation of soil profile and associated pollutant removal mechanism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Database approach for estimating pollutant reduction</td>
</tr>
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</table>
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2. Watershed models
3. BMP models
4. Decision Support System
5. Implication
BETTER ASSESSMENT SCIENCE INTEGRATING POINT AND NONPOINT SOURCES

Spatial Data
- Land Use/Land Cover
- Surface Waters
- Roads
- Boundaries

Monitoring Data
- WQ Monitoring
- Bacteria
- NSI

Sources of Pollution
- PCS
- TRI
- Superfund

Assessment Tools
- TARGET
- ASSESS
- Data Mining
- Ws Delineation
- Reporting
- Import local data

TMDL Watersheds Source water protection

Watershed and Water Quality Modeling
- NPSM
- TOXIROUTE
- QUAL2E

Decisions

Notes:
a BASINS GIS Environment
b Windows-based Interface
c Windows Shell w/FORTRAN
- **BMP design**
  - Properly size and configure practices
  - Evaluate effectiveness of BMP after design and construction
- **Site development**
  - Evaluate effectiveness of multiple practices for hydrology and water quality
  - Optimize selection and placement of practices
- **Watershed management**
  - Analyze watershed-wide implementation
    - Program evaluation
    - CSO reduction
    - TMDL compliance
BMP-Decision Support System (BMP-DSS)

Data Collection (GIS and Field Testing)
Field Reconnaissance

- Land cover map
- Land ownership map
- 2-ft contour map
- Soil data
- Groundwater level
- Underground utility data
- Drainage area delineation

Potential BMP/LID Types & Sites

Design Storm Approach

BMPDSS Optimization

Runoff Characterization
BMP Performance Evaluation
BMP Cost Estimation

Recommended BMP/LID Conceptual Plan
Selected BMP Types

Bioretention

Pervious Pavement
- Choker Course: AASHTO No.57
- Sufficient to fill large aggregate space
- Clean uniformly graded coarse aggregate, AASHTO No.3
- Bed depth varies, generally 12" - 36"
- Non-woven Geotextile on bed bottom and sides

Landscape Infiltration

Infiltration Swale
- Stabilize with seed and curlex
- Bioretention soil mixture
- 2"-3" of wash gravel
- 4" high strength perforated PVC pipe under drain and outfall at existing storm drain
- 12" of # 57 stone for additional storage of storm and groundwater

Filter Swale Cross Section

Section Not to Scale
SUSTAIN Components

Framework Manager (ArcGIS)

- Watershed Module
- BMP Module
- BMP Siting Tool
- Optimization
- Cost Database
- Interpretation (Post Processor)
Define BMP Details by SUSTAIN

Define BMP Cost Function

\[ \text{Cost} = (Aa \times \text{Area}) \times (Da \times \text{Depth}) \]

where

- \( Aa \) = area excavated for BMP
- \( Da \) = average depth of soil excavated
- \( \text{Land Cost} \) = unit cost of land ($/ft²)
- \( \text{Fixed Cost} \) = fixed cost ($), and

\( Aa, Da, Ds, Db \) are coefficients of the cost function.

Cost Parameters:

- \( Aa = 1.3 \)
- \( Da = 1 \)
- \( \text{Land Cost} = 10 \)

Total Cost ($): \[ 4365 \]

BMP Parameters:

- Name: BioRetentionBasin1
- Basin Dimensions:
  - Length (ft): 10
  - Width (ft): 10

Surface Storage Configuration:

- Exit Type:
  - Release Option:
    - Option 1
    - Option 2

Weir Configuration:

- Weir Type:
  - Rectangular Weir
    - Weir Crest Width (ft): 1
  - Triangular Weir
    - Weir Height (Hw, ft): 0.5
    - Vertex Angle (theta, deg):
Figure 17: Comparison of BMP optimal and design solutions, and pollutant reduction vs. cost trade-off curve.
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Future Enhancement - I

• Structured to allow users to select BMP types at various spatial scales
More Capabilities

- Add BMP simulation techniques for emerging technologies/recent research;

- Add optimization alternatives;

- Provide the ability for users to add their own bmp formulations as a discrete module (requires developing a generic interface and data exchange tool);
Future Enhancement - III

More Ground-Truth and Testing

- Additional applications in diverse urban settings (could be co-sponsored by other groups);

- Evaluate performance using recent BMP specific monitoring studies.
Thank you!

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