Understanding the Key Drivers for Effective Mitigation of Runoff with Vegetative Filter Strips

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Organization of Presentation

• VFS Overview
• Key Drivers
• Prediction tools for pesticide mitigation in runoff
VFS Overview

• Retention/Detention:
  – Infiltration
  – Hydraulic Resistance

• Advantages:
  – Overland flow and dissolved pollutants reduction and delay
  – Decrease in sediment transport capacity
  – Sediment/particles deposition
Key Drivers: Hydrologic Response

- Infiltration is governed by...
  - Soil physical properties
  - Vegetative cover
  - Antecedent moisture content
  - Rainfall intensity/Inflow
  - Slope and width
- Hydraulic resistance a function of...
  - Vegetation type and characteristics
  - Inflow volume
  - Slope and width

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Quantifying Hydrologic Response

• Infiltration:
  – Easier to quantify for uniform infiltration into homogenous soil
  – Additional complexity with macroporosity and preferential flow

• Hydraulic Resistance/Surface Flow:
  – Easier to quantify for sheet flow
  – Additional complexity with concentrated flow/flow convergence

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Hydrologic Drivers

\[ \Delta Q = \text{Infiltration} = (\text{Runoff Entering} + \text{Precipitation}) - \text{Runoff Leaving} \]

\[ \Delta E = \text{Sedimentation} = \text{Sediment Entering} - \text{Sediment Leaving} \]
Key Drivers for Effective Mitigation

Key Drivers: Sediment/Contaminant

• Contaminant Property (Pesticide):
  – Phase distribution factor
    \[ K_d = \frac{K_{oc}(\%OC)}{100} \]
    \[ F_{ph} = \frac{Q_i}{K_d E_i} \]
    \[ K_{oc} = \text{organic carbon sorption coefficient} \]
    \[ K_d = \text{distribution coefficient} \]

• Sediment:
  – Percent clay content of incoming sediment
Prediction Tools for Diffuse Contaminants

- Largely based on physical characteristics of the buffer system...
  - SWAT - Buffer width: $\Delta P = 0.367(W_B)^{0.2967}$
  - USDA suggests correlation between percent pesticide reduction and $K_{oc}$
  - Liu and others (2008) - Correlation to buffer slope and width – $R^2 = 0.23$

$\Delta P = $ Pesticide Reduction (%)
Key Drivers for Effective Mitigation

Survey of Literature

• Effectiveness of VFS compiled from 127 published journal articles

• Event-scale studies
  – 5 publications for model development
  – 5 publications for model evaluation
Model Development Dataset

- 47 observations: alachlor, atrazine, chlorpyrifos, metolachlor, and permethrin
- $\Delta P$ ranging from 22 to 100%
- VFS widths ranged from 3.0 to 20.1 m (VFS width in the primary direction of flow)
- Natural and simulated rainfall and runoff events
- Soils with % clay content from 21 to 30%
Model Development

\[ \Delta P = f(\Delta Q, \Delta E, \ln(F_{ph} + 1), \%C) \]

- Buffer width not statistically significant predictor
- Buffer width captured by \( \Delta Q \)
Model Analysis – $K_{OC}$

- High mobility pesticides (low $K_{OC}$)  
  - $\Delta Q$ - Infiltration

- Low mobility pesticides (high $K_{OC}$)  
  - $\Delta E, F_{ph}$ – Sedimentation, Phase Distribution Factor
Model Evaluation Dataset

- 120 measured $\Delta P$ ranging from 8.0 to 100%
- Atrazine, cyanazine, diflufenican, isoproturon, lindane, metolachlor, metribuzin, pendimethalin, and terbuthylazine
- VFS widths ranged from 0.5 to 20.1 m
- Soils with % clay content from 12 to 45%
Buffer Width Equation (SWAT)

- Does not adequately predict VFS efficiency by itself

\[ \Delta P = 0.367(W_B)^{0.2967} \]
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Model Evaluation

- Improved prediction capability by accounting for hydrologic response
Use of Empirical Equations

- Parameters for estimating $\Delta P$, such as $\Delta Q$ and $\Delta E$, not easily predicted
- Uncalibrated VFS model that predicts $\Delta Q$ and $\Delta E$
  - Vegetative Filter Strip Modeling System, VFSMOD
  - Finite-element, field-scale, storm-based model

- Routes incoming hydrograph and sedigraph
- Infiltration - Green-Ampt
- Sediment trapping - GRASSF
VFSMOD Critical Parameters

- Soil Hydraulic Parameters ($K_{sat}$, $\theta_o$ and $\theta_s$)
  - Impacts infiltration

- Roughness Coefficient (Manning’s $n$)
  - Impacts hydraulic resistance
  - Impacts timing of the peak runoff and not the total runoff volume
  - Default values of Manning’s $n$ for closest vegetation type
VFSMOD Critical Parameters

- Rainfall volume and duration and entering runoff volume and duration
- Concentration of sediment in the entering runoff ($C_s$)
- Characteristics of the sediment
- Characteristics of the VFS
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VFSMOD – ΔQ and ΔE

- VFSMOD able to predict runoff and sediment reduction

![Graph showing runoff and sediment reduction](image)
• Combined VFSMOD/empirical equation able to predict VFS performance
Potential Questions

• What about the effect of flow uniformity?
  – Can the procedure account for concentrated flow?

• Are the empirical regression parameters transferable?
  – Evaluation with additional data sets
Chlorpyrifos/Atrazine Study

- Two Factors:
  - Flow Volume
  - Sheet vs. Concentrated Flow
Chlorpyrifos/Atrazine Study

- VFSMOD able to predict uniform and concentrated flow runoff
Chlorpyrifos/Atrazine Study

- VFSMOD able to predict sediment reduction

![Graph showing the relationship between predicted and measured sediment reduction. The graph includes a linear regression line with a slope of 1.12, an intercept of -14.81, and an R² value of 0.85. Concentrated flow with 10% of plot width and uniform flow with 100% of plot width are highlighted.]
Chlorpyrifos/Atrazine Study

- Combined VFSMOD/empirical equation able to predict VFS performance
Chlorpyrifos/Atrazine Study

- Treatment effects for pesticide reduction (%):
Conclusions

• Key Drivers: Hydrologic response
• Physical VFS characteristics and pesticide reduction correlations insufficient to predict buffer efficiency in practice
• Combined mechanistic model (VFSMOD) with empirical trapping efficiency equation
  – Appropriate for both uniform and concentrated flow
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Questions?