Fundamentals of Nutrient Management

ENVIRONMENTAL MANAGEMENT

Jason A. Hubbart, Ph.D.
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West Virginia University
Davis College of Agriculture, Natural Resources and Design
Institute of Water Security and Science
Presentation Topics:

• Hydrologic cycle and relationship of ground and surface waters
• Effects of nutrients in ground and surface waters
• Factors causing the decline of the Chesapeake Bay
• Nutrient loss mechanisms to ground and surface waters
• Identification of environmentally sensitive site features
• Nutrient management practices for environmentally sensitive sites
• Critical times when nutrient losses are most likely to occur
• Use of cropping systems to reduce nutrient losses
My approach this afternoon...
Hydrologic cycle and relationship of ground and surface waters

1. The Hydrologic Cycle
2. The Water Budget
3. Introduction to Precipitation Processes
4. Phase Changes of Water
5. Let’s Make Rain!
6. Canopy Interception
7. Runoff and Groundwater

- Key Contexts(s):
  - Precipitation supplies the transport mechanism for pollutants
  - Physical processes govern biological systems
The Hydrologic Cycle

Citation
Introduction to the Watershed Mass Balance

\[ \Delta S = P + Qin - Qout - ET + Gin - Gout = \Delta S \]
Surface Terrain Inconsistencies
Introduction to the Energy Balance Equation

- **Energy Balance Equation:**
  - $\Delta S = R_{\text{net}} + L_{\text{vE}} + H + G + M$

- **where:**
  - $\Delta S$ = change in storage (energy)
  - $R_{\text{net}}$ = net radiation
  - $L_{\text{vE}}$ = latent heat of vaporization
  - $H$ = sensible heat
  - $G$ = ground (or surface) energy
  - $M$ = advected energy
Mass and/or Energy Balance – How to Calculate?

• Why calculate?

• How do you calculate?

• What do they tell you?

• How are they related?

• How do you quantify the variables if you have no data?
  – $\Delta S = P + Qin - Qout - ET + Gin - Gout$
  – $\Delta S = Rnet + LvE + H + G + M$
Phase Changes of Water in the Atmosphere

- **Water Mass Balance Equation:**
  \[
  \Delta S = P + Qin - Qout - ET + Gin - Gout
  \]

- We need to estimate precipitation to:
  - Estimate water availability
  - Estimate pollutant transport
  - **Must have rainfall to get runoff!**
What is Air?

<table>
<thead>
<tr>
<th>Component</th>
<th>% by Vol.</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₂</td>
<td>78.08</td>
</tr>
<tr>
<td>O₂</td>
<td>20.95</td>
</tr>
<tr>
<td>H₂O</td>
<td>0 - 4</td>
</tr>
<tr>
<td>Ar</td>
<td>0.934</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.0325</td>
</tr>
</tbody>
</table>

![Diagram of air composition]
Vapor Pressure

- Partial pressure of H₂O in air is the vapor pressure.
- Units of pressure are: Pascals (Pa)
  M L⁻¹ T⁻² : kg m⁻¹ s⁻²
- Also expressed in bars, millibars (mb)
  1 bar = 100,000 Pa = 1x10⁵ Pa
  1 mb = 100 Pa = 1x10² Pa
- Less frequently
  - atm, psi, inHg, inH₂O
Vapor Pressure Relations

Saturation vapor pressure at 0°C: 611 Pa

Air Undersaturated With Respect to Water

Air Supersaturated With Respect to Water
Saturation Vapor Pressure Curve

Can be approximated by:

\[ e_s = \exp \left( 21.382 - \frac{5347.5}{T} \right) \]

vapor pressure in mb

temperature in \( K \)

Or, use published vapor pressure tables!

• Note: There are many valid methods of approximating saturation vapor pressure.
More Vapor Pressure Relations

Relative humidity: \( RH = \left( \frac{e_{aTa}}{e_{s(Ta)}} \right) \times 100\% \)
Measures of Humidity: in Brief

• Vapor pressure (\(e_a\))
  – partial pressure of \(H_2O\) vapor in air
    \[ e_a = RH(e_{s(Ta)}) \]

• Relative humidity: \(RH = \left(\frac{e_{Ta}}{e_{s(Ta)}}\right) \times 100\%\)

• Vapor pressure deficit: \(\delta e = e_{s(Ta)} - e_{Ta}\)
  \[\delta e = e_{s(Ta)}(1 - RH/100)\]

• Dew point temperature (\(T_d\)):
  – The temperature to which a parcel of air has to be cooled at constant pressure to reach saturation
  – Compute by solving the saturation vapor pressure equation, or use tables
The Lapse Rate

• As one goes up in elevation, it gets colder
  Usually! Exceptions ??

• By how much?
  – 9.8 °C/km… ~1°C per 100m
  – Under dry, adiabatic conditions
  – Dry: moisture is not changing
  – Adiabatic: energy is not changing

• Note!!
  – The environmental lapse rate is usually less than the adiabatic lapse rate

• 0.65 °C per 100m
How Does Precipitation Form?

• Three primary conditions:
  – Atmosphere becomes saturated
    • Humid air mass must be lifted
    • By lifting, air cools
    • Saturation is reached
  – Nuclei must be present
  – Water particles collide and coalesce to form droplets
Processes that Produce Uplift

• Fronts
  – Warm front rides over cold dry air
  – Incoming cold front pushes warm, wet air up

• Orography – induced by mountains
  – Warm, moist air rises over mountains releases water
  – Cool, dry air falling from mountains has little moisture
    – rain shadow

• Convection
  – Warm air rises, cools, and forms thunderstorms

• Convergence – occurs in tropics
Frontal Precipitation

Warm and Moist

COLD

COLDER
Orographic Precipitation

AIR MASS

SNow

Rain

Rainshadow

Ocean
Convective Precipitation

Air near ground warms and rises

Air rises and cools reaching saturation

Condensation of rising Air produces clouds…
Convergence

- Typically occurs in the tropics.
- A horizontal net inflow of air into a region.
- Air converges along the surface
- Forced to rise since it cannot go downward.
Precipitation Descriptors

• Amount of precipitation – units of depth (L)
• The duration of event - time
• Intensity = amount/duration
  – May be for all or part of the total duration
    • seconds, minutes, hours, days, years, ...
  – Long durations have greater amounts …
  – Shorter durations have greater intensities

• Seasonal Distributions

• PPT = 35 to 50 inches/year, long term average in the Chesapeake Bay Watershed
• ET = 20 to 35 inches/year
Canopy Interception

- Dominant component of evaporative loss in forests
  - 5% - 40% of gross rainfall!
  - Negative interception ?! What?
    - Fog/cloud interception and condensation can be significant
    - Reduces rainfall intensity and erosivity
- Foliage wetness duration also very important
  - Decreases transpiration losses
  - Fungal pathogens
- Stemflow – minor component
**Interception**: The process by which precipitation is retained by a vegetation canopy

**Net Precipitation**: The amount of precipitation that reaches the soil
Terminology

Canopy Interception Loss (Ec)

Gross Rainfall (R)

Saturation Storage Capacity (S)

Stemflow (Rs) Canopy Throughfall (Rc) Direct Throughfall (Rd)

Net Throughfall (Rt)

Litter Interception Loss (Ei)

Modified from Dingman, 1994, Physical Hydrology
**Terminology**

- **Interception**: The process by which precipitation falls on vegetative surfaces.
- **Net Precipitation**: The amount of precipitation that reaches the soil.
- **Gross rainfall**: The rainfall measured above canopy or in the open.
- **Direct Throughfall**: Proportion of rainfall that passes through a canopy without being detained, “free throughfall”.
- **Canopy Throughfall**: Proportion of rainfall that contacts the canopy before reaching the ground.
- **Stemflow**: The water that reaches the ground surface by running down trunks and stems.
- **Net Throughfall**: The rainfall that reaches the ground surface directly through canopy spaces, by canopy drip, and stemflow.
Event-scale Throughfall
What Controls Interception?

- **Storage Capacity**: The depth of water that can be detained on a plant surface in still air [0.5 – 5.0 mm, higher for conifers].
- **Ratio of Evaporating Area**: i.e. canopy closure
- **Evaporation During Rainfall**: evap can occur when it’s raining !!
- **Storm Duration**
- **also**: Controlled by canopy structure:
  - Species
  - Density
  - Leaf area
  - Canopy epiphytes
Interception is a major component of the hydrologic cycle.

Interception losses can range from <0%, to ~100%.

Losses are dependent on:
- Canopy structure
- Storm duration
- Meteorological conditions during and between events

Additional losses occur from forest litter.
Infiltration, Runoff and Groundwater

\[ \text{Precipitation (P)} = \text{Runoff (Q)} + \text{Interflow (Q_int)} + \text{Transpiration (T)} + \text{Evaporation (E)} + \text{Drainage (G)} + \Delta \text{SM} \]

\[ \Delta \text{SM} = P - Q - G - ET \]

- Precipitation (P)
- Runoff (Q)
- Interflow (Q_int)
- Transpiration (T)
- Evaporation (E)
- Drainage (G)
- Infiltration (G)
- Baseflow (Q_{GW})
Infiltration: The process by which water enters soil
  – Driving Forces:
    – Gravity
    – Capillarity

Percolation/redistribution: Downward and lateral movement of water in soil

Infiltration Capacity: Maximum steady state infiltration rate
  – Infiltration rate can exceed infiltration capacity under positive pressure (i.e. ponding)
  – Infiltration rate decreases as qv increases
Importance of Infiltration

- Overland flow = Precipitation – Infiltration – Detention
- Impacts hydrologic regime
- Overland flow causes erosion
- Erosion leads to sedimentation in streams
- Negative impact on water quality
- Land Use Affects Infiltration Processes !!

When rainfall > infiltration capacity, ponding, or overland flow occurs…
What Influences Infiltration...

Factors affecting water movement through soils.
If infiltration capacity is exceeded:

1. Excess precipitation fills detention storage
2. Excess precipitation becomes overland flow
## Example Infiltration Rates (mm hr⁻¹)

<table>
<thead>
<tr>
<th>Soil</th>
<th>Bare Soil</th>
<th>Row Crops</th>
<th>Poor Pasture</th>
<th>Good Pasture</th>
<th>Forested</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse-medium texture over sand/gravel</td>
<td>8</td>
<td>13</td>
<td>15</td>
<td>25</td>
<td>76</td>
</tr>
<tr>
<td>Fine-textured over fine textured till</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>
Surface water

• Watershed – area of land draining into a stream at a given location

• Streamflow – gravity movement of water in channels
  – Surface and subsurface flow
  – Affected by climate, land cover, soil type, etc.
Surface (Hortonian Runoff)

Example #1

- Infiltration Rate = rainfall rate, which is less than infiltration capacity

Example #2

- Runoff Rate = rainfall rate minus infiltration capacity
Runoff on saturated areas (Hewlett)
Variable Source Area Concept

Start of storm
1 day of rain
2 days of rain
Hydrograph Components
Land Use Impacts to the Hydrograph

Diagram showing:
- Stream discharge over time
- Comparison of discharge before and after urbanization with and without detention basins or flood-control reservoirs
- Controlled outflow from detention basin or flood-control reservoir after urbanization
Variable Flowpaths of Surface and Groundwater
Assessing Impairment and Loading

Combined water and sediment quality

Is water use attained?
  no

Is non-use due to natural sources only?
  no

Water body is polluted
  Abatement is required

yes

Water body is NOT polluted

Source: Novotny and Olem (1994)
Estimating Loading

• Mass Loading = Concentration x Flow
  \[ \frac{M}{T} = \frac{M}{L^3} \times \frac{L^3}{T} \]

• Total Maximum Daily Load
  \[ \text{TMDL} = \text{WQS} \times Q \]

• TMDL Definition: The maximum amount of a pollutant a body of water can receive while still meeting WQS
Major sources for nutrients: Fertilizer, feedlots, sewage, and discharge from wastewater treatment plant, others...

Major problems caused by high concentrations of nutrients: Cultural eutrophication (well-fed by nutrient) - which leads to growth of algae bloom, triggering biological oxygen demand (BOD) problem

The algae covering the surface of water, block sunlight to plant below and consuming oxygen, killing the underlying plants.

Algae die, float/sink and consume oxygen through decomposition.
Groundwater Pollution

- Agricultural products
- Underground storage tanks
- Landfills
- Septic tanks
- Surface
- Impoundments
Oxygen-depleted Water in the Gulf of Mexico
Chesapeake Bay

• Largest US estuary
• Pollution “sink”
• Oxygen depletion
• Chesapeake Bay Program
Factors causing the decline of the Chesapeake Bay

Chesapeake Bay Watershed

Chesapeake Bay and its Streams

Economy, heritage, quality of life.

Data Source: Chesapeake Bay Program
For more information, visit www.chesapeakebay.net
Data Source: www.chesapeakebay.org/tnm/tnm08base_Mtn

Created by EA, 1/24/08
UTM Zone 18N, NAD 83
Factors causing the decline of the Chesapeake Bay

**Land & People**
- Population growth
- Development
- Impervious surfaces
- Storm water

**Climate Change**
- Sea level rise
- Warmer water temperature
- Fewer underwater grasses
- Larger dead zones
- Fewer wintering waterfowl
- Influx of new species

**Air & Water Pollution**
- Nitrogen & Phosphorous
- Sediment
- Chemical Contaminants

**Natural Factors**
- High temperatures
- Strong storms
- Inconsistent freshwater flows

**Fisheries Harvest**
- Disease
- Overharvesting
GOALS & OUTCOMES

WATER QUALITY

Restoring the Bay's waters is critical to overall watershed restoration because clean water is the foundation for healthy fisheries, habitats and communities across the region. However, excess amounts of nitrogen, phosphorus, and sediment in the Bay and its tributaries have caused many sections of the Bay to be listed as "impaired" under the Clean Water Act. The Chesapeake Bay Total Maximum Daily Load (TMDL) is driving nutrient and sediment reductions as described in the Watershed Implementation Plans (WIPs), adopted by the states and the District of Columbia, and establishes the foundation for water quality improvements embodied in this Agreement. These plans set nutrient and sediment reduction targets for various sources—stormwater, agriculture, air deposition, wastewater, and septic systems.

GOAL: Reduce pollutants to achieve the water quality necessary to support the aquatic living resources of the Bay and its tributaries and protect human health.

2017 Watershed Implementation Plans (WIP) Outcome

By 2017, have practices and controls in place that are expected to achieve 60 percent of the nutrient and sediment pollution load reductions necessary to achieve applicable water quality standards compared to 2009 levels.

2025 WIP Outcome

By 2025, have all practices and controls installed to achieve the Bay's dissolved oxygen, water clarity/submerged aquatic vegetation and chlorophyll a standards as articulated in the Chesapeake Bay TMDL document.

Water Quality Standards Attainment and Monitoring Outcome

Continually improve the capacity to monitor and assess the effects of management actions being undertaken to implement the Bay TMDL and improve water quality. Use the monitoring results to report annually to the public on progress made in attaining established Bay water quality standards and trends in reducing nutrients and sediment in the watershed.
TMDL Timeline (CBP)

• 1999 – Lawsuit by American Canoe Association and American Littoral Society
• 2010 – TMDL put in place
• 2017 MidPoint Assessment
  – 60% of the management practices implemented
  – Improved models
  – Mid-Course Correction?
• 2025 TMDL Goal Date
  – 100% of the management practices implemented
  – Improved models?
  – Other new information ????
Agricultural and urban land use practices are often associated with excessive SS and nutrient pollution (there are many other sources)

- **Agricultural impacts include:**
  - Deforestation
  - Crop fertilizer application
  - Soil disturbance
  - Animal waste

- **Urban impacts include:**
  - Land clearing
  - Lawn fertilizer application
  - Increased impervious surfaces
  - Stormwater runoff
  - Wastewater inputs

(Carpenter et al, 1998)
Identification of environmentally sensitive site features

Start of storm
1 day of rain
2 days of rain
Where to focus efforts: Critical Source Areas

- Areas within a watershed that are most polluting and require pollution elimination
- Determination and location of critical source areas is one of the most important tasks in planning diffuse-pollution abatement
- Examples: urban subdivisions, sanitary landfill, and farmer’s fields
Nutrient management practices for environmentally sensitive sites:

OR: Control of NPS Pollution

- Control of NPS pollution requires understanding of chain of processes which produce pollution
  - Limit availability or exposure to transporting water
  - Timing of hydrologic events
  - Geographic location

Lot’s of information available:
NRCS / EPA / USGS / USFS / MRB / CBP / USDA / CA / DEP / DNR / WV DA ....
Definition of BMP

- Best Management Practices: a practice or set of practices determined to be the most effective, practical means of preventing or reducing NPS pollution. "Practical" includes physical, chemical, biological, cultural and economic aspects.
Better Management Practices?

• Best implies that the suggested practice is actually best – best for what purpose or outcome?
  – Best for engineering purposes?
  – Most economical?
  – Most ecologically sensitive?
  – Most socially acceptable?

• Best may imply total or perfect knowledge concerning the system of interest and definition of the problem; such knowledge doesn’t exist.

• One size doesn’t fit all!

• Take-Home Message: Understand the system you are working in.
Critical times when nutrient losses are most likely to occur

• Consider the transport mechanism and when transport is occurring:
  – When / Where / How much?

• Unless transport is occurring, do we worry about excess nutrient concentrations or loads?
Two main nitrogen losses from agriculture

• Nitrate leaching in drainage water causes pollution of surface and groundwater

• Nitrous oxide (N2O) is given off by soil and is a potent greenhouse gas.

• Consider the circumstances under which they move = critical times of loss
Inappropriate farming practices

- Soil degradation
- Soil erosion
- Loss of organic matter
- Soil compaction
- Acidification
- Loss of nitrates, phosphates, and pesticides
- Accumulation of salts and trace elements
- Increased run-off of fertilizers and pesticides to water systems
Soil Degradation Processes

• Three Primary Processes
  – Physical
    • Wind erosion
    • Water erosion
    • Compaction
  – Chemical
    • Toxification
    • Salinization
    • Acidification
  – Biological
    • Declines in organic matter
    • Declines in carbon
    • Declines in the activity and diversity of soil fauna
Rotational Cropping

• Can play significant role in conserving soil, maintaining soil fertility, controlling pests, and also helps break up insect and disease cycles
Cover Crops

- Cover crop of small grains, meadow, or hay planted in the fall after harvest of a row crop provides vegetative cover to reduce soil loss, hold nutrients, add organic matter to the soil, and sequester carbon
Crop Residue Management (CRM)

- CRM leaves crop residues on soil surface through less intensive tillage practices.
  - Usually cost effective
  - Protects soil surface
  - Leads to higher farm economic returns
Conservation buffers and Structures

- Structures and buffers reduce water erosion caused by rainfall
- Very important component of farm soil management systems
Reducing Nutrient Loss: The 4R’s of Nutrient Stewardship

• Improve agricultural production while contributing to social well being and minimizing environmental impacts (benefits water and air quality)

• 4R represents the use of fertilizer Best Management Practices to ensure:
  – the right source
  – at the right rate
  – at the right time
  – in the right place
The concept is simple –
- apply the right source of nutrient
- at the right rate
- at the right time and
- in the right place
- But the implementation is knowledge-intensive and site specific.
What is Nutrient Management?

- Simple in concept?
- Combined on-farm nutrient sources, with commercial fertilizer, to meet crop need.

Minimize nutrient losses

- On-farm nutrient sources (manure)
- Soil reserves
- Commercial fertilizer
Water resource issues are complex and highly interconnected. So, try to plan carefully...

Water Quantity

- Water Quality
- Municipal Use
- Navigation
- Irrigation
- Dams and Development
- Bulk Removal & Export
- Groundwater
- Climate Change
- Non-Native Species
- Biodiversity
- Wetlands

Water Quality

- Safe Drinking Water
- Toxic Substances
- Sabotage
- Recreation
- Shoreline Erosion
- Drought
- Flooding
- Municipal Water and Wastewater
- Fish Habitat

Water resource issues are complex and highly interconnected. So, try to plan carefully...
To properly manage watersheds for water quality, you will have to identify the need(s).

- Development of water quality management plans, i.e. TMDL’s
- Must identify the watershed area contributing to water body
- Identify proper loading allocation for individual land owners
- Identify the critical areas in watersheds
Critical Source Areas for Water Quality

Hydrologically Active Areas

Critical Source Zones

Pollutant Loading Areas

Watershed
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