Environmental Water Quality
BAE 452/552

Session 15

Loading Functions, Solid-phase and Dissolved Chemical Loads

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Transport of Pollutants & Loading Calculations

- Mass balance & hydrologic components
- Erosion and sediment transport
- Loading calculations
- Solid-phase and dissolved chemical loads ←
- Distributed-phase chemical loads
- Salt loads in irrigation return flows & urban runoff loads
- Ground water waste loads

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"EPA Document"

http://www.epa.gov/waterscience/pc/watqual.html

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Principle Pollutants

- Solid-phase: strongly associated with sediment
- Dissolved chemical loads: dissolved in runoff
- Distributed-phase chemical loads: significant chemical quantities are transported in both solid-phase and dissolved forms

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Dissolved Waste Loads (in runoff)

- Dissolved Pollutant Waste Load (LD):

$LD = 0.1\ C_d\ Q$

where

LD is dissolved chemical load in runoff (kg/ha)

C_d is concentration of dissolved chemical in runoff (mg L^{-1})

Q is runoff from source area (cm)

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SCS Curve Number Method

- A standard procedure for estimating storm runoff:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \text{ for } P \geq 0.2S$$

where

Q = runoff (cm)

P = precipitation (rainfall + snowmelt, cm)

S = water retention parameter (cm)

0.2S = initial precipitation abstraction

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SCS CN Method (addendum)

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \text{ for } P \geq 0.2S$$

For a single rainfall event, you cannot apply the equation to individual time increments because it assumes storage never fills

Instead, you have to accumulate the rainfall and apply the abstraction against that cumulative rainfall.

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Example

	CN	AMC	S - cm	0.2*S
	80	II	6.35	1.27

Time hours	Rainfall cm	Cumulative rain - cm	Cumulative excess - cm	Incremental excess - cm
0	0.00	0.00	0.00	0
1	0.51	0.51	0.00	0.00
2	1.78	2.29	0.14	0.14
3	0.94	3.23	0.46	0.32
4	2.64	5.87	1.93	1.47
5	5.94	11.81	6.58	4.65
6	1.63	13.44	7.99	1.42
7	0.18	13.61	8.15	0.16
	13.61			

Watershed Runoff

- Runoff from an entire watershed is the sum of runoff from all source areas within a watershed

$$Q = \sum_k a_k Q_k$$

where Q_k = runoff from source area k (cm)

a_k = fraction of watershed covered by source area k = A_k/A_{tot}

A_k = area of source area k (ha)

A_{tot} = total watershed area (ha)

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Solid Phase Waste Loads (in runoff)

- Solid Phase Pollutant Waste Load (LS):

LS = 0.001 C_{sed} X

where

LS is solid-phase chemical load in runoff (kg/ha)

C_{sed} is concentration of chemical in eroded soil (sediment) (mg kg^{-1})

X = soil loss (t ha^{-1})

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Watershed Sediment Yield

Annual yields due to surface erosion:

$$Y = SDR \sum_k A_k X_k$$

where

- Y is annual sediment yield (tons yr^{-1})
- X_k = erosion from source k by RUSLE
- A_k = area of source area k (ha or acre)
- SDR = watershed sediment delivery ratio

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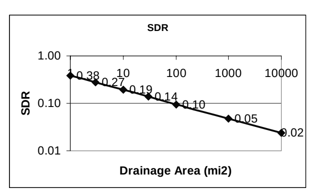
Sediment Delivery Ratio

- Many relationships exist. Presented here:

$$SDR = 0.38 A_t^{-0.3}$$

where A_t = watershed area (mi^2)



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Example

Compare annual soil erosion in southern Louisiana for a corn field with no conservation practices and with contouring and the following characteristics:

Soil: silt loam, 4% organic matter

Slope: 6%, Length: 100 m (=328 ft)

Moderate productivity, residues left, fall turn-plowed conventional management

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Example Solution

EI (english) from Figure 2-1 (Handbook 703) or from Figure III-10 (EPA document): EI = 500

EI (metric) = 1.735*500 = 868 (= R-factor)

K-factor from Table III-3 (EPA document): 0.33

C-factor from Table III-4 (EPA document): 0.52

P-factor from Table III-9 (EPA document):

P = 1.0 for no practice, P = 0.5 for contouring

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Example Solution

LS-factor:

- $L = [\lambda/72.6]^m$
- $m = \beta/(1+\beta)$

$$\beta = \frac{11.16 \sin\theta}{3.0(\sin\theta)^{0.8} + 0.56}$$

- 6% slope, so $\theta = \tan^{-1}(0.06) = 3.43°$, $\beta = 0.90$, $m = 0.47$
- $L = [328/72.6]^{0.47} = 2.05$
- $S = 10.8 \sin\theta + 0.03$ for $\sin\theta < 0.09$, $S = 0.68$
- LS = 2.05*0.68 = 1.39

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Example Solution

Soil loss X = 1.29 R K L S C P

- For no conservation practice:

$X = 1.29(868)(0.33)(1.39)(0.52)(1.0) = 267.0$ t ha^{-1}

- For contouring:

$X = 1.29(868)(0.33)(1.39)(0.52)(0.5) = 133.6$ t ha^{-1}

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Solid-Phase Chemical Load

Organic Nitrogen and Particulate Phosphorus

- $LS = 0.001\, C_{sed} X$

where

- $C_{sed} = ER\, C_s$

where

- ER = nutrient enrichment ratio
- C_s = nutrient concentration in in-situ soil (mg kg^{-1})

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Solid-Phase Chemical Load

Nitrogen:

- C_s obtained from measurements, using isotherm data (see Session 11), or
- $C_s = 0.05(\%OM/100)10^6 = 500(\%OM)$

where

- %OM = percent organic matter in the soil, or
- $C_s = (\%N)10^4$ from Parker map

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Solid-Phase Chemical Load

Phosphorus:

- C_s obtained from measurements, using isotherm data (see Session 11), or
- $C_s = 0.44(\%P_2O_5)10^4$ from Parker map

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Enrichment Ratio

Concentration of the contaminant on sediment in runoff divided by concentration in parent soil

ER > 1:

- Selective removal of fine materials with higher pollutant concentrations

ER = 2 for annual loads

$ER = 7.39/Sed^{0.2}$ for event loads, where Sed (1000 X) is in kg ha^{-1}

If for X>22 t/ha, set ER = 1.0

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Enrichment Ratio

For phosphorus (Sharpley, 1980) proposed:

$$\ln(ER) = a_o + a_1 \ln(TSS)$$

where

$a_0 \approx 2.2$

$a_1 \approx -0.24$

For a variety of soil and cover conditions in east and mid-west states. Confirmed for one western location by Sanchez and Boll (2002)

Sharpley, A.N. (1980) JEQ 9:521-526, Sanchez and Boll (in progress)

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Solid-Phase Chemical Load

Heavy metals:

- $LS = 0.001\ C_{sed}X$

where

- C_{sed} = typical concentrations found in soil (see Table III-11 in EPA document)
- Examples:
- Copper (18 ppm), Iron (18,000 ppm), Lead (16 ppm), Zinc (44 ppm)

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Watershed Solid-Phase Load

Annual watershed load:

$$WLS = SDR \sum_k LS_k A_k$$

$$WLS = 0.001\ SDR \sum_k C_{sed,k} A_k X_k$$

where

- k = source k

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Example

The West Branch Delaware River is an 85,000 ha watershed in south-central NY, that drains into the Cannonsville Reservoir. Soil erosion is a major phosporus source to the reservoir. The R factor in english units is 125. Land use is as follows:

Corn	3,430 ha	KLSCP=0.214
Hay	13,085 ha	KLSCP=0.012
Pasture	5,093 ha	KLSCP=0.016
Inactive Ag	3,681 ha	KLSCP=0.017
Logging Roads	20 ha	KLSCP=0.217

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Example

- Determine average annual solid-phase phosphorus input to the reservoir (kg yr^{-1}).
- $LS = 0.001\ C_{sed}\ Y$
- where $Y = SDR \sum_k A_k X_k$

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Example Solution

R = 1.735x125 = 217

	X_k=1.29RKLSCP (t ha^{-1})
Corn (3,430 ha)	1.29(217)0.214=59.9
Hay (13,085 ha)	3.4
Pasture (5,093 ha)	4.5
Inactive Ag (3,681 ha)	4.8
Logging Roads (20 ha)	60.7

$SDR = 0.38\ (850x1/1.6^2)^{-0.3} = 0.0665$

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Example Solution

Y = 0.0665[3,430(59.9) + 13,085(3.4) + 5,093(4.5) + 3,681(4.8) + 20(60.7)] = 19,425 t yr^{-1}

Phosphorus Load:

$C_s = 0.44(0.15)10^4$ = 660 mg/kg with ER = 2 (annual load), C_{sed} = 2(660) = 1320 mg kg^{-1}

Assuming C_{sed} is the same for all source areas (!),

$LS = 0.001\ C_{sed}\ Y$

LS = 0.001(1320)(19,425) = 25,641 kg yr^{-1}

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Dissolved Chemical Waste Loads (N and P)

- Dissolved Pollutant Waste Load (LD):

$LD = 0.1\ C_d\ Q$

where

C_d can be found using measurements, using isotherm data, or

C_d can be found from Table III-12 in EPA document

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Dissolved Chemical Waste Loads (phosphorus)

- Alternative Dissolved Pollutant Waste Load (LD):

LD = 0.001 Q LSoilP XC

where

XC = extraction coefficient

LSoilP = labile soil P (mg kg^{-1})

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Dissolved P Concentration

- Sharpley (1985) proposed*: $C_d = \frac{KC_s \rho_{dry} Dt^{\alpha} W^{\beta}}{Q}$

where

ρ_{dry} = dry bulk density (Mg m^{-3})

D = effective depth of interaction between surface soil and runoff (mm)

t = runoff event duration (min)

W = runoff water/soil (TSS) ratio

Q = total runoff during event (mm)

K, α, β = constants

* for individual runoff event, C_d in mg L^{-1}

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Dissolved P Concentration

for a range of soil types:

$K = 0.029 - 0.071$

$\alpha = 0.094 - 0.195$

$\beta = 0.240 - 0.794$

Sharpley, A.N. 1985. SSSAJ 49:1010-1015

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Watershed Dissolved Chemical Load

Watershed load is sum of source loads:

$$WLD = 0.1 \sum_k C_{d,k} Q_k A_k$$

where

- k = source k

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Example III-5 (EPA document)

During the growing season, a 7.0 cm rainstorm falls on the Louisiana cornfield in the previous example (A = 10 ha, OM=4%). Given is that storm runoff = 4.9 cm (CN method), and soil loss = 30 t/ha for event. Total soil loss = 300 tonnes.

Determine solid-phase and dissolved nitrogen in runoff (in kg).

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Example III-5 Solution

Solid Phase N Load:

$LS = 0.001\ C_{sed}\ X$ with $C_{sed} = ER\ C_s$

$C_s = 0.05(\%OM/100)10^6 = 0.05(0.04)10^6 = 2000$ mg kg^{-1}

$ER = 7.39/(1000X)^{0.2} = 7.39/(1000(30))^{0.2} = 0.94 \Rightarrow 1.0$

$C_{sed} = 1.0(2000) = 2000$ mg kg^{-1}

LS = 0.001(2000)30 = 60 kg/ha or 600 kg for 10 ha field

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Example III-5 Solution

Dissolved N Load:

$LD = 0.1\ C_d\ Q$

C_d from Table III-12 (EPA document) = 2.9 mg L^{-1} (corn)

Q = 4.9 cm

LD = 0.1(2.9)4.9 = 1.4 kg/ha or 14 kg for 10 ha field

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