Environmental Water Quality
BAE 452/552

Session 18

Urban Runoff Loads

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Urban Runoff

- Urban runoff rates are usually higher than rural runoff rates due to the distribution of impervious surfaces (pavement, roofs, etc.)
- Urban runoff is collected in storm sewers or combined sewers (runoff and sanitary wastewater)
- To avoid flooding, combined sewer overflows are discharged directly to receiving waters (most polluting!)

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Urban Runoff Quality

- Urban runoff quality is influenced by human activities: land use and population density
- Like in rural areas, land uses may be considered "source areas"
- Total runoff load is sum of runoff loads from each land use

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Typical Urban Land Uses

- Residential (low, medium, high density)
- Commercial
- Industrial
- Other (large parking areas, sport complexes)
- Open lands (parks, golf courses, idle lands)
- Transportation (airport, railroad, roads)

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Urban Runoff Loads

- Annual loading for separate and combined sewer loads
- Event loading for separate sewer loads

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Annual Urban Runoff and Combined Sewer Loads

General urban loading function:

- $L_k = \alpha_k F_k \gamma_k P$

where

- L_k = annual load of pollutant due to runoff from land use k (kg ha^{-1})
- α_k = pollutant concentration factor (kg ha^{-1}cm^{-1})
- F_k = population density function
- γ_k = street cleaning factor
- P = annual precipitation (cm)

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Annual Urban Runoff and Combined Sewer Loads

General urban loading function:

- $L_k = \alpha_k F_k \gamma_k P$

where

- α_k = a concentration
- $F_k P$ = a water flux
- γ_k = an attenuation factor

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Annual Urban Runoff and Combined Sewer Loads

Total urban loading function:

- $L = \Sigma L_k A_k$

where

- L = annual load of pollutant due to runoff (kg)
- A_k = area of land use k (ha)

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Annual Urban Runoff and Combined Sewer Loads

P is obtained from local weather data

α_k is obtained from Table III-20 in EPA document

$$F_k = \begin{cases} 1.0 \text{ for commercial and industrial} \\ 0.142 + 0.134\, PD^{0.54} \text{ for residential} \\ 0.142 \text{ for other urban areas} \end{cases}$$

PD = population density (persons/ha)

$\gamma_k = N_s/20$ for $N_s < 20$ (N_s = street cleaning interval)

$\gamma_k = 1.0$ for $N_s > 20$ (N_s = street cleaning interval)*

* for combined sewers, $\gamma_k = 1.0$

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Example III-8

Estimation of Annual Urban Pollutant Loads

- Consider a city of 4000 ha of which 20% is commercial, 10% industrial, 65% residential, and 5% in other developed areas. The residential PD = 25 persons/ha. Most of the city has separate sewers but 30% has combined sewers. Streets are swept every 5 days in commercial and industrial areas and not in residential areas. Mean annual P is 105 cm. Determine the average annual loads of N and P.

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Event Loads in Urban Runoff

Follows procedure in U.S. Army Corps of Engineers urban runoff model STORM (Storage, Treatment, Overflow, Runoff Model)

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Event Loads in Urban Runoff

Similarly formulated as solid-phase rural runoff loads:

- $L = 10^{-6}\, C\, Y$

where

- L = pollutant load in urban runoff (kg ha^{-1})
- Y = sediment washed off the urban area during runoff event (kg ha^{-1})
- C = pollutant concentration in sediment (mg kg^{-1})

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Event Loads in Urban Runoff

Urban wash-off (limited by total sediment on surfaces):

- Y = W X

where

- X = accumulated sediment at the time of a storm (kg ha^{-1})
- W = fraction of X which washes off during the storm

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Event Loads in Urban Runoff

The washoff function: $\frac{dX(h)}{dh} = -uqX(h)$

where $X(h) = X(0)e^{-u\int q dh}$

- X(h) = sediment remaining on the land surface at hour h after the beginning of a storm (kg ha^{-1})
- X(0) = accumulated sediment at the beginning of the storm (kg ha^{-1})
- q = runoff rate (cm hr^{-1})
- u = washoff coefficient (cm^{-1})

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Event Loads in Urban Runoff

The integral is the total storm runoff up to hour h. If Q = total storm runoff (cm):

$$X(h) = X(0)e^{-uQ}$$

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Event Loads in Urban Runoff

The washoff coefficient is determined assuming 90% of accumulated sediment is washed off with 0.5 inches (1.27 cm) of runoff. Thus:

$$0.1X(0) = X(0)e^{-1.27u}$$ or u = 1.8 cm^{-1}

The fraction of sediment washed off is:

$$W = \frac{X(0) - X(h)}{X(0)} = 1 - e^{-1.8Q}$$

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Event Loads in Urban Runoff

Finally, the sediment in runoff can be predicted as:

$$L = 10^{-6}(1 - e^{-1.8Q})CX$$

If applied to area with multiple land uses k:

$$L = \sum_k a_k L_k$$

or if Q is equal for each land use k:

$$CX = (\sum_k a_k C_k)(\sum_k a_k X_k)$$

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Urban Runoff

Determination of runoff amounts:

- Runoff CN method (discussed previously, Table III-21 provides CN)
- Runoff coefficients (CR) and depression storage (DS, cm):

  Q = CR(P - DS) for P > DS

where

P = storm precipitation (rainfall + snowfall, cm)

(see EPA document for further details on this method)

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Sediment

To estimate C and X, we first need the sediment or solids accumulation. Sediment (and pollutant) accumulation depends on:

- daily deposition from atmosphere and other sources
- removal by street cleaning
- washoff by runoff

Rate of accumulation can be measured from TSS in storm sewers.

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Sediment

Daily sediment build-up (normalized by length of street curbing):

$x = z\, C_l$

where

x = daily sediment build-up (kg ha^{-1} day^{-1})

z = sediment accumulation rate (kg km^{-1} of curb per day)

C_l = curb length density (km ha^{-1}) = (2x total street length/area) or use Equation III-67

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Daily Sediment Mass Balance

$X_{t+1} = X_t + x - Y_t - S_t$

where

X_t = accumulated sediment at beginning of day t (kg ha^{-1})

Y_t = sediment removed in runoff on day t (kg ha^{-1})

S_t = sediment removed by street cleaning on day t (kg ha^{-1})

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Daily Sediment Mass Balance

$X_{t+1} = X_t + x - Y_t - S_t$

$Y_t = (1 - e^{-1.8Q(t)})\, X_t$

If streets are cleaned on day t, $S_t = e\, X_t$

where

e = street cleaning efficiency (fraction removed by cleaning)

(Streets are not cleaned on rainy days)

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Daily Sediment Mass Balance

$$X_{t+1} = x + (e^{-1.8Q(t)} - e)\, X_t$$

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Example III-9

Urban Sediment Accumulation and Removal

A storm occurs on May 31 which removes all sediment from an urban area. Subsequent storms occur on June 9 and June 15 which produce 0.5cm and 1.1cm of runoff, respectively. On June 6, the streets are cleaned with an efficiency e=0.4. The daily build-up is x = 80 kg ha^{-1}. How much sediment is contained in the runoff from the June 15 storm?

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Pollutant Concentration

Determined by:

- Sampling of sediment in street gutters
- Sampling storm sewer flows
- For conventional pollutants see Table III-23 (EPA document)
- For metals and organic compounds see Table III-24 and 25

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SWMM

- Storm Water Management Model (EPA)
- http://ccee.oregonstate.edu/swmm/
- http://www.computationalhydraulics.com/consultant/archive

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Street Cleaning

- http://www.slough.gov.uk/LocalEnvironment/streetcleaning.asp
- http://www.schmidt.co.uk/en/products/swingo.html

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NURP

- EPA's NURP Program: Nationwide Urban Runoff Program

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