CIEG 440 Water Resources Engineering G. J. Kauffman

Module 6 - Water Quality Engineering

Water resources engineering includes water quantity and water quality analyses.

Pollutant loads to streams are contributed by point sources (PS) and nonpoint sources (NPS). Point sources flow from end of pipe such as wastewater treatment plants, industries, and superfund hazardous waste sites. Nonpoint sources flow from diffuse, sheet flow such as agriculture and urban/suburban runoff.

In 1972 the Federal Clean Water Act was passed mandating that the nation's waterways should become fishable and swimmable. Since that time much of the CWA funding has gone toward cleaning up point sources such as wastewater treatment plant (WWTP) improvements. For instance, modernization of the WWTPs that flow into the Delaware River near Philadelphia have increased dissolved oxygen levels thus removing the "oxygen block" and allowing for a return of the migratory shad fishery. This is a real success story of the Clean Water Act.

In 2003, much of the Clean Water Act funding is applied toward reducing nonpoint sources of priority pollutants such as Bacteria, Total Suspended Sediment, Nitrogen, and Phosphorus. Water resources engineers are often retained to conduct watershed estimates of pollutant loads and design best management practices that can reduce the flow of priority pollutants such as Bacteria, TSS, N, and P into the streams.

1. Simplified Method

The "simplified method" is a first generation, desk top model that can be used to estimate pollutant loads in various watersheds:

$L = (A)\,(P)\,(R)\,(C)\,(0.2260)$ (Schueler, 1987)

Where:

L = Annual pollutant load, lb/yr.

A = watershed area, acres.

P = Mean annual precipitation, in. (In northern Delaware this is 41 inches at Wilmington Airport)

R = Runoff coefficient for various land uses (see Table 1 for TSS).

C = Mean pollutant concentration (mg/l) (see Table 1 for TSS)

Table 1
Total Suspended Sediment Load Variables

Land Use	Mean TSS Concentration (C) (mg/l)	Runoff Coefficient (R)
Single family residential (1/2 acre/DU and greater)	140	0.30
High Density/Multi-family resid.	180	0.65
Office	175	0.60
Industrial	251	0.72
Transportation/Utility	350	0.90
Commercial	168	0.85
Institutional	128	0.55
Open Space/Parks	20	0.20
Wooded/Forested	20	0.20
Agriculture	300	0.30

Sources: NURP/USEPA (1983), Bannerman (1992), USEPA (1993)

Example: Compute the TSS Load from the Panther Run watershed (198 ac).

Given:	Forest	= 99 ac.
	Residential, ½ ac. Lots	= 16 ac.
	Agriculture, hay	= 83 ac.

Lforest	= A P R C (0.226)	
	= (99 ac) (41 in.) (0.20) (20 mg/l) (0.226)	= 3,669 lb/yr
Lresidential	= (16 ac) (41 in) (0.30) (140 mg/l) (0.226)	= 6,226 lb/yr
Lagriculture	= (83 ac) (41 in) (0.30) (300 mg/l) (0.226)	= 69, 217 lb/yr
Total		= 79,112 lb/yr

Total = 79,112 lb/yr / 198 ac. = 399 lb/ac/yr.

TSS loads from watersheds of the Christina Basin in northern Delaware range from 311 to 975 lb/ac/yr depending on the amount of impervious and forested cover in the watershed (Table 2). Panther Run which has a fairly high amount of agriculture but is buffered by large areas of forest cover, generates TSS loads which are in the low to middle range of the streams in the Christina Basin.

Table 2
Estimated Total Suspended Sediment Loads in the Christina Basin in Northern Delaware

	B16. Brandywine Creek above Wilmington	B17. Brandywine Creek below Wilmington	R3. Burroughs Run	R4. Red Clay Creek above Wooddale	R5. Red Clay Creek below Wooddale	W5. Mill Creek	W6. Pike Creek	W7. Middle Run	W8. White Clay Creek above Newark	W9. White Clay Creek below Newark	W10. White Clay Creek Tidal	C1. Upper Christina River above Cooches Bridge	C2. Muddy Run	C4. Little Mill Creek	C5. Christina River below Newark	C6. Tidal Christina below Smalley's Pond
Total Suspended Sediment (lb/ac/yr)	345	975	481	316	506	530	483	428	311	759	792	651	421	654	633	928

Source: UDWRA, 2003

2. Best Management Practices

Water resources engineers are often retained to design best management practices to reduce pollutant loads flowing into waterways. Table 3 summarizes the median pollutant removal efficiencies of various BMPs depending on the pollutant of concern.

Table 3
Best Management Practice Pollutant Removal Efficiencies

Pollutant	Dry Ponds	Wet Ponds	Wetlands	Filters/Bioswales	Infiltration
Bacteria	78%	70%	78%	37%	5%
Total Phosp.	19	51	49	59	70
Nitrate Nitrgen	4	43	67	14	82
TSS	47	80	76	86	95
Cu	26	57	40	49	N/A
Zn	26	66	44	88	99

Source: Center for Watershed Protection, 2000

Suppose a wet pond is constructed at the downstream end of the Panther Run watershed. Estimate the pollutant removal efficiency for TSS and estimate inflow and outflow sediment loads.

Wet Pond TSS Pollutant Removal Efficiency = 80% (not 57%, note the change from class notes)
Inflow Sediment Load = 399 lb/ac/yr
Outflow Sediment Load = 399 – 0.80(399) = 399 – 319 = 80 lb/ac/yr.

3. **Simple Dilution Model**

The Simple Dilution Model can be used to evaluate the allocation of pollutant loads on streams:

(Ldownstream * Qdownstream) = (Lsource * Qsource) + (Lupstream * Qpstream)

Where:
Ldownstream = Pollutant load in stream downstream from source (lb/ac/yr)
Qdownstream = Flow in stream downstream from source (cfs)

Lsource = Pollutant load from source watershed or discharge (lb/ac/yr)
Qsource = Flow from source watershed or discharge (cfs)

Lupstream = Pollutant load in stream upstream from source (lb/ac/yr)
Qupstream = Flow in stream upstream from source (cfs)

Example: Estimate the dilution of TSS loads entering the White Clay Creek from Panther Run

Given:
Lsource = 399 lb/acyr
Lupstram = 200 lb/ac/yr
Qsource = 100 cfs
Qupstream = 1000 cfs

(Ldownstream * 1100 cfs) = (399 lb/ac/yr)(100 cfs) + (200 lb/ac/yr)(1000 cfs)

Ldownstream = (39900 + 200,000)/1100 cfs = 218 lb/ac/yr

4. Total Maximum Daily Loads

In 1997, Delaware and Pennsylvania consented with the U. S. Environmental Protection Agency to establish low flow and high flow Total Maximum Daily Loads (TMDLs) in the Christina Basin. The low flow (point source) TMDLs were issued by the USEPA in October 2002. USEPA expects to complete the high flow (stormwater) TMDLs by December 2004. TMDLs are established along impaired waterways in accordance with Section 303(d) of the Federal Clean Water Act. TMDLs are determined using hydrologic and hydraulic computer models according to the following equation:

TMDL = WLA + LA + FS

Where:
TMDL = Maximum amount of a particular pollutant discharged to a waterway without violating stream water quality standards

WLA = The waste load allocation from point sources such as wastewater treatment plants during low flow conditions

LA = Load allocation from nonpoint sources such as stormwater and agricultural runoff during high flow conditions

FS = Factor of safety to account for imprecision in modeling and monitoring

Low Flow TMDL
In October 2002 USEPA issued the low flow TMDL for the Christina Basin. The TMDL calls for eight wastewater dischargers to reduce chemical/biological oxygen demand (CBOD5), Nitrogen (NH3-N), and Total Phosphorus (TP) loads in accordance with the amounts listed in Figure 4. Necessary reductions in pollutant loads will be accomplished as part of renewal of NPDES discharge permits.

Table 4
Reduction in TMDL of Nutrients and Dissolved Oxygen under Low Flow Conditions in the Christina Basin

NPDES Facility	**Permit Number**	**Flow (mgd)**	**Level 1 and 2 Reduction**		
			CBOD5	NH3-N	TP
East Branch Brandywine Creek					
Broad Run Sew. Co	PA0043982	.4	8%	0%	6%
Sonoco Products	PA0012815	1.028	28%	28%	28%
Downingtown Area Reg. Auth.	PA0026531	7.134	36%	36%	36%
West Branch Brandywine Creek					
PA American Water Co.	PA0026859	3.85	28%	0%	28%
NW Chester Co. Mun. Auth.	PA0044776	.6	10%	10%	10%
West Branch Red Clay Creek					
Kennett Square	PA0024058	1.1	34%	34%	34%
Sunny Dell Foods, Inc.	PA0057720-001	.05	5%	5%	5%
West Branch Christina River					
Meadowview Utilities, Inc.	MD0022641	.7	0%	69%	0%

5. Compute Impervious Cover

Compute the composite impervious cover of each watershed utilizing an EXCEL spreadsheet model (Bowers, Greig, and Kauffman, 1998) according to the following formula:

%IMP = [(SFR Area)(SFR Imp) + (MFR Area)(MFR Imp) + (OC Area)(OC Imp) + (IND Area)(IND Imp) + (TU Area)(TU Imp) + (INS Area)(INS Imp) + (POS Area)(POS Imp) + (WOD Area)(WOD Imp) + (AGR Area)(AGR Imp) + (WW Area)(WW Imp) + (VAC area)(Vac Imp)]/ Watershed area

Where:

%IMP	= Composite impervious cover of a particular watershed.
SFR Area, etc.	= Area (acres) of each land use within watershed.
SFR Imp	= 30%
MFR Imp	= 65%
OC Imp	= 60%
IND Imp	= 72%
TU Imp	= 90 %
INS Imp	= 85%
POS Imp	= 0%
WOD Imp	= 0%
AGR Imp	= 0%
Watershed area	= Total acres within a particular watershed.

- Single Family Residential, 1/2 to 2 acre lots (SFR)
- Multi-Family Residential (MFR)
- Office/Commercial (OC)
- Industrial (IND)
- Transportation/Utility (TU)
- Institutional (INS)
- Public Open Space (POS)
- Wooded (WOD)
- Agriculture (AGR)
- Water/Wetlands (WW)
- Vacant (VAC)

For example, compute the impervious cover of the 198-acre Panther Run watershed, with 98 acres wooded, 16 acres single family residential ½ acre/du, and 83 acres agriculture.

%IMP = [(98 acres)(0%) + (16 acres)(30%) + (83 acres)(0%)]/198 acres

%IMP Panther Run Watershed = [0 + 480 + 0]/198 ac = 2.4 %

One should note that this methodology employs estimates of characteristic imperviousness which can vary depending on the density of particular land uses. Therefore these impervious cover estimates are precise to the nearest whole number and certainly to the range of the nearest even 5%. The above calculation of 2.4% is precise to the nearest 2% or 3% and certainly more precise within the range of 0 to 5%.