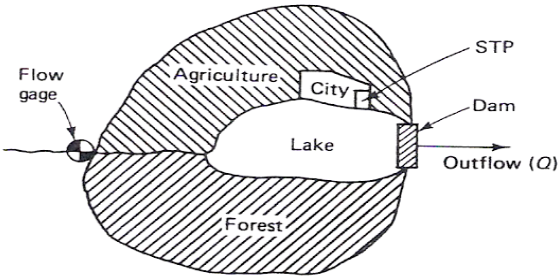
Fonte: Thomann & Mueller. Principles of Surface Water Quality Modeling and Control.

SAMPLE PROBLEM 7.1

DATA



Lake Geometry

$$\text{volume } (V) = 6.22 \times 10^8 \text{ m}^3$$
$$\text{surface area } (A) = 7.77 \times 10^7 \text{ m}^2$$
$$\text{depth } (H) = 8 \text{ m}$$

Sewage Treatment Plant (STP)

population served = 50,000
water use = 150 gcd
influent Tp = 6 mg/l
plant removal = 20%

Combined Sewers (CSO)

runoff coefficient (C) = 0.45
service area = 6 mi^2
capture by STP = 5%
overflow Tp concentration = 4 mg/l

Storm Drains (SW)

service area = 4 mi^2
runoff coefficient = 0.27
Tp concentration = 0.7 mg/l

Upstream Gage

annual average flow = 500 cfs
Tp (virgin land) = 0.02 mg/l

Sample Problem 7.1 (continued)

Agricultural Land

$$\text{draingage area} = 60 \text{ mi}^2$$
$$\text{Tp loading} = 0.5 \text{ lb/mi}^2\text{-day}$$
$$\text{runoff} = 30\% \text{ rainfall}$$

Forest

$$\text{draingage area} = 80 \text{ mi}^2$$
$$\text{Tp loading} = 0.15 \text{ lb/mi}^2\text{-day}$$
$$\text{runoff} = 30\% \text{ rainfall}$$

PROBLEM

The lake basin receives 30 in./yr of rainfall. On an annual average basis estimate the total phosphorus (Tp) concentration in the lake.

ANALYSIS

Lake Outflow

Assume precipitation onto the lake surface and evaporation from the surface are equal and do not affect the hydrologic balance. Thus, the upstream flow plus the sum of the incremental flows from the areas draining to the lake equals the outflow.

$$Q(\text{STP}) = 50{,}000 \text{ cap} \times 150 \text{ gcd} \times \text{MGD}/10^6 \text{ gal} \times 1.548 \text{ cfs/MGD} = 11.6 \text{ cfs}$$

$$Q(\text{CSO}) = \text{CIA}(1 - \text{capture}) = 0.45 \times (30 \text{ in/yr} \times 1 \text{ yr}/365 \text{ days} \times 1 \text{ day}/24 \text{ hr} = 0.00342 \text{ in./hr}) \times (6 \text{ mi}^2 \times 640 \text{ acre/mi}^2 = 3840 \text{ acres}) \times (1 - 0.05) = 5.61 \text{ cfs}$$

$$Q(\text{SW}) = 0.27 \times \left(\frac{30}{365 \times 24}\right) \times (4 \times 640) = 2.36 \text{ cfs}$$

$$Q(\text{agricultural}) = (30 \times 0.3) \text{ in./yr} \times \frac{0.07367 \text{ cfs/mi}^2}{\text{in./yr}} \times 60 \text{ mi}^2 = 39.8 \text{ cfs}$$

$$Q(\text{forest}) = 30 \times 0.3 \times 0.07367 \times 80 = 53.0 \text{ cfs}$$

$$\therefore Q = 500 + 11.6 + 5.61 + 2.36 + 39.8 + 53.0 = 612 \text{ cfs}$$

$$\underline{Q} = 612 \text{ cfs} \times \frac{1 \text{ m}^3/\text{s}}{35.4 \text{ cfs}} = \underline{17.3 \text{ m}^3/\text{s}}$$

(continued)

Sample Problem 7.1 (continued)

Lake Tp Loading

$$W(\text{STP}) = 11.6 \text{ cfs} \times [6(1 - 0.20)\text{mg/l}] \times 5.4 \frac{\text{lb/day}}{\text{mg/l-cfs}}$$

$$= 301 \text{ lb/day}$$

$$W(\text{CSO}) = 5.61 \times 4 \times 5.4 = 121 \text{ lb/day}$$

$$W(\text{SW}) = 2.36 \times 0.7 \times 5.4 = 9 \text{ lb/day}$$

$$W(\text{upstream}) = 500 \times 0.02 \times 5.4 = 54 \text{ lb/day}$$

$$W(\text{agricultural}) = 0.5 \text{ lb/mi}^2\text{-day} \times 60 \text{ mi}^2 = 30 \text{ lb/day}$$

$$W(\text{forest}) = 0.15 \times 80 = 12 \text{ lb/day}$$

$$\therefore W = (301 + 121 + 9 = 431) + (54 + 30 + 12 = 96)$$

$$= \underline{527 \text{ lb/day}}$$

Areal Loading

$$W = 527 \text{ lb/day} \times 365 \text{ days/yr} \times 454 \text{ g/lb} = 8.73 \times 10^7 \text{ g/yr}$$

$$W' = W/A_s = 8.73 \times 10^7/7.77 \times 10^7 = 1.12 \text{ g/m}^2\cdot\text{yr}$$

Lake Tp Concentration

$$t_d = \text{hydraulic detention time} = \frac{V}{Q}$$

$$t_d = \frac{6.22 \times 10^8 \text{ m}^3}{17.3 \text{ m}^3/\text{s}} \times \frac{1 \text{ yr}}{3.154 \times 10^7\text{s}} = 1.14 \text{ yr}$$

$$q = \text{overflow rate} = \frac{Q}{A_s} = \frac{1}{V/H \cdot 1/Q} = \frac{H}{t_d} = \frac{8 \text{ m}}{1.14 \text{ yr}} = 7.02 \text{ m/yr}$$

Assume a net loss rate of Tp(v_s) = 12.4 m/yr.
∴ Total phosphorus concentration (p) is

$$p = \frac{W'}{q + v_s} = \frac{1.12 \text{ g/m}^2\cdot\text{yr}}{7.02 \text{ m/yr} + 12.4 \text{ m/yr}} \qquad \text{[Eq. (7.5)]}$$

$$\underline{\underline{p}} = 0.058 \text{ g/m}^3 = 0.058 \text{ mg/l} = \underline{\underline{58\ \mu\text{g/l}}}$$

Notes: The concentration of 58 μg/l would place the lake in the eutrophic status (see Table 7.1 and Fig. 7.12).

Since the range of net loss rates is quite large (≈ 1 m/yr to ≈ 20 m/yr), Fig. 7.13, lake specific data should be used to estimate this parameter.

Reductions in the urban sources would be more effective than reductions in the rural sources since the urban sources amount to (431 lb/day ÷ 527 lb/day) or 82% of the total lake loading.