

Environmental Engineering FE CBT Exam

Knowledge: Surface Water Resources and Hydrology with 20 Example Problems

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1 Exam Scope and Hydrologic Thinking

The FE Environmental specification divides this domain into five connected tasks: runoff calculations; storage sizing; routing; water quality/modeling; and water budget. Most questions can be reduced to one of three patterns: a *mass balance*, a *rainfall-runoff transformation*, or a *transport/decay relation*.

Core framework

$$\text{Input} - \text{Output} \pm \text{Reaction} = \text{Change in Storage}$$

Hydrology problems often replace “reaction” with losses such as infiltration and evapotranspiration.

Common FE cues

- “Peak flow” usually signals the Rational Method when a runoff coefficient and rainfall intensity are supplied.
- “Runoff depth” from a rainfall depth and curve number signals the NRCS/SCS method.
- “At least once in n years” signals return-period probability.
- “Required reservoir capacity” or “detention storage” signals continuity/storage accounting.
- “Minimum dissolved oxygen downstream” signals Streeter–Phelps.

Exam habit: identify the requested quantity and units before searching the handbook. The FE handbook provides many formulas, but the problem statement may supply coefficients or assumptions not in the handbook.

1.1 Watersheds, Drainage Areas, and Hydrologic Response

A watershed is the land area draining to a common outlet. The watershed boundary follows topographic divides. Hydrologic response depends on drainage area, slope, surface roughness, soil, land cover, antecedent moisture, and the drainage network.

Key distinctions

- **Rainfall depth** P has units of length (in., mm).
- **Rainfall intensity** i has units of length/time (in./hr, mm/hr).
- **Runoff depth** Q_r is an equivalent depth over the watershed.
- **Discharge** Q has units of volume/time (cfs, m³/s).

To convert a runoff depth to a runoff volume,

$$V = d_r A$$

with consistent units. In USCS, 1 acre-in. = 3,630 ft³ and 1 acre-ft = 43,560 ft³.

Hydrologic response: Increasing impervious area generally reduces infiltration, shortens travel time, increases peak discharge, and increases runoff volume. Storage and roughness tend to attenuate and delay peaks.

Composite watershed idea. If different land uses occupy fractions of a basin, use area-weighted parameters when the method permits:

$$C_{comp} = \frac{\sum C_i A_i}{\sum A_i}, \quad CN_{comp} = \frac{\sum CN_i A_i}{\sum A_i}.$$

1.2 The Hydrologic Cycle and Water-Budget Equation

For a surface-water system, the FE Reference Handbook gives the hydrologic budget in the form

$$P + Q_{in} - Q_{out} + Q_g - E_s - T_s - I = \Delta S_s.$$

Here P is precipitation input, Q_{in} and Q_{out} are surface-water flows, Q_g is groundwater input to the stream, E_s is evaporation, T_s is transpiration, I is infiltration, and ΔS_s is change in surface-water storage.

Equivalent generic form

$$\Delta S = \sum \text{inflows} - \sum \text{outflows}.$$

Sign convention: define all inflows as positive and outflows as negative. A positive ΔS means storage increases.

Steady-state simplification. If the control volume is in long-term steady state, $\Delta S \approx 0$ and total inflows equal total outflows.

Unit strategy

- If all terms are depths over the same basin, keep them as in./month or mm/year.
- If flow rates are given, multiply by the time interval to obtain volumes before combining with storage.
- Convert evaporation or infiltration depths to volumes using $V = dA$ when needed.

Frequent trap: adding a flow rate directly to a volume. Convert each term to a common basis first.

2 Precipitation: Depth, Intensity, Duration, and Frequency

Design storms are described by **intensity**, **duration**, and **frequency** (IDF). For a fixed return period, short-duration storms often have higher average intensity than long-duration storms.

If rainfall intensity is approximately constant,

$$P = it,$$

where P is depth, i is intensity, and t is duration.

Return period and annual exceedance probability

$$p = \frac{1}{T},$$

where T is the return period in years and p is the probability the event is equaled or exceeded in any one year.

The probability of at least one exceedance in n years is

$$P_{\geq 1} = 1 - \left(1 - \frac{1}{T}\right)^n.$$

Interpretation: a “100-year storm” does not mean one event exactly every 100 years. It means a 1% annual exceedance probability under the assumed stationary frequency model.

Rational Method linkage. The design rainfall intensity is commonly selected for a duration equal to the watershed time of concentration, t_c , because that is the duration needed for the entire contributing area to affect the outlet simultaneously.

2.1 Time of Concentration

The **time of concentration** t_c is the travel time for runoff from the hydraulically most remote location in a watershed to reach the design point. It sets an important time scale for peak-flow calculations.

The FE handbook presents a storm-sewer form

$$t_c = t_i + t_s,$$

where t_i is inlet/overland-flow time and t_s is sewer-flow time. One empirical inlet-time relation in the handbook is expressed in terms of travel length L , land slope S , rainfall intensity i , and a coefficient C .

Conceptual effects on t_c

- Steeper slope $\rightarrow$ faster travel $\rightarrow$ smaller t_c .
- Smoother/impervious surface $\rightarrow$ faster travel $\rightarrow$ smaller t_c .
- Longer flow path $\rightarrow$ larger t_c .
- Added detention/storage $\rightarrow$ delayed hydrograph response.

Rational Method rule: use the rainfall intensity corresponding to a storm duration at least as long as t_c . On the FE exam, the problem often gives an IDF relation or directly provides the intensity at t_c .

Do not confuse: t_c describes travel/response time; it is not the same as the total storm duration unless the design setup makes them equal.

2.2 Rational Method

The FE Reference Handbook gives

$$Q_p = CIA,$$

where Q_p is peak discharge (cfs), C is runoff coefficient, I is rainfall intensity (in./hr), and A is watershed area (acres). In these USCS units, the numerical conversion is effectively embedded in the equation.

Physical meaning

- C represents the fraction of rainfall intensity that becomes direct runoff at peak conditions.
- I should correspond to the selected return period and a duration related to t_c .
- A is the contributing drainage area.

Composite coefficient

$$C_{comp} = \frac{C_1 A_1 + C_2 A_2 + \cdots}{A_T}.$$

Then use $Q_p = C_{comp} I A_T$.

Typical exam interpretation: higher imperviousness increases C and therefore increases Q_p linearly if I and A remain unchanged.

Limitations to remember. The method is primarily a peak-flow method and does not directly produce a full hydrograph or runoff volume. It is best suited to relatively small drainage areas under the assumptions provided in the problem.

2.3 Runoff Coefficients and Land Use

The FE handbook includes runoff-coefficient ranges for land uses such as business districts, residential areas, industrial areas, lawns, pavement, roofs, agricultural land, and woodlands.

Qualitative ordering

$$C_{roof/pavement} > C_{dense\ urban} > C_{residential} > C_{lawns/woods}.$$

For a mixed basin,

$$C_{comp} = \sum_i C_i f_i, \quad f_i = \frac{A_i}{A_T}.$$

Sensitivity: Because $Q_p = CIA$, a 20% increase in C produces a 20% increase in peak flow if I and A are unchanged.

Exam strategy

1. Compute each area fraction.
2. Multiply each fraction by its runoff coefficient.
3. Sum to obtain C_{comp} .
4. Confirm C_{comp} lies between the smallest and largest component values.

Common error: averaging the C values without weighting by area. Equal averaging is only valid when the land-use areas are equal.

2.4 NRCS/SCS Curve Number Method

The FE handbook provides the NRCS/SCS rainfall–runoff relation

$$Q_r = \frac{(P - 0.2S)^2}{P + 0.8S}, \quad P > 0.2S,$$

with

$$S = \frac{1000}{CN} - 10$$

when P , Q_r , and S are in inches. If $P \leq 0.2S$, direct runoff is taken as zero under the standard formulation.

Interpretation

- High $CN \rightarrow$ low storage potential $S \rightarrow$ more runoff.
- Low $CN \rightarrow$ high $S \rightarrow$ less runoff.
- CN captures land cover, hydrologic soil group, and hydrologic condition.

Initial abstraction: $I_a = 0.2S$ in the standard equation shown in the FE handbook. It represents interception, depression storage, and other losses before runoff begins.

Composite curve number

$$CN_{comp} = \frac{\sum CN_i A_i}{A_T}.$$

Use the composite CN to calculate S and then runoff depth.

2.5 Runoff Volume from Curve Number Results

After calculating runoff depth Q_r , convert it to volume:

$$V_r = Q_r A.$$

For USCS convenience,

$$V_r(\text{ft}^3) = Q_r(\text{in.}) \left(\frac{1 \text{ ft}}{12 \text{ in.}} \right) A(\text{acres})(43,560 \text{ ft}^2/\text{acre}).$$

Equivalently,

$$V_r(\text{acre-ft}) = \frac{Q_r(\text{in.})}{12} A(\text{acres}).$$

Runoff coefficient vs. curve number

- Rational Method: peak discharge, coefficient C .
- Curve Number Method: runoff depth/volume, parameter CN .

Useful exam check: runoff depth cannot exceed rainfall depth. If your calculation gives $Q_r > P$, revisit the arithmetic or units.

Post-development comparison. A higher post-development CN typically increases runoff volume. Detention may reduce the peak discharge, but unless infiltration or another loss is added, detention by itself does not eliminate the storm runoff volume; it redistributes discharge over time.

3 Hydrographs and Effective Rainfall

A hydrograph plots discharge versus time. Key features are rising limb, peak discharge, recession limb, and baseflow. Direct runoff hydrographs represent the storm response above baseflow.

Effective rainfall is the portion of precipitation remaining after hydrologic losses and available to become direct runoff.

A hydrograph volume is the area under the discharge curve:

$$V = \int Q(t) dt.$$

For a triangular hydrograph,

$$V = \frac{1}{2} Q_p t_b,$$

where t_b is base duration (use consistent time units).

Important distinction: peak discharge is a rate; hydrograph volume is the time integral of that rate. Two hydrographs can have the same runoff volume but different peaks.

Hydrologic effects

- Urbanization tends to create a steeper rising limb, earlier peak, and larger peak.
- Detention tends to flatten and delay the peak.
- Infiltration and evapotranspiration reduce runoff volume.

3.1 Unit Hydrographs

A unit hydrograph is the direct-runoff hydrograph produced by one unit depth of effective rainfall applied uniformly over a watershed for a specified duration. The FE handbook gives a triangular unit-hydrograph peak relation

$$q_p = \frac{484AQ_r}{T_p},$$

where q_p is peak discharge (ft^3/s), A is drainage area (mi^2), Q_r is runoff depth (in.), and T_p is time to peak (hr).

Principles

- **Proportionality:** doubling effective rainfall depth doubles the direct-runoff ordinates, assuming linear response.
- **Superposition:** hydrographs from successive rainfall pulses may be shifted and added.
- **Time invariance:** the watershed response is assumed not to change during the event.

FE focus: use a supplied unit hydrograph or the handbook relation to obtain a peak or scale hydrograph ordinates. Do not confuse total precipitation with effective rainfall.

If a 1-in. unit hydrograph has peak q_1 , then a d -in. effective-rainfall pulse of the same duration produces peak contribution dq_1 before superposition effects.

3.2 Return Period and Risk Over a Project Life

For a return period T , annual exceedance probability is

$$p = \frac{1}{T}.$$

Assuming independent annual events, the probability of no exceedance in n years is

$$P_0 = \left(1 - \frac{1}{T}\right)^n.$$

Therefore,

$$P_{\geq 1} = 1 - P_0 = 1 - \left(1 - \frac{1}{T}\right)^n.$$

Example interpretation. For $T = 25$ years and $n = 10$ years,

$$P_{\geq 1} = 1 - (24/25)^{10} \approx 0.335.$$

So the chance of at least one 25-year exceedance during a 10-year period is about 33.5% under the model assumptions.

Common trap: n/T is not the exact probability of at least one occurrence. Use the complement formula.

This concept appears in design-risk questions for stormwater infrastructure, reservoirs, flood-control works, and temporary facilities.

4 Infiltration and Soil-Moisture Concepts

Infiltration is the movement of water from the land surface into soil. During a storm, runoff begins when rainfall supply exceeds the combined capacity of interception, depression storage, infiltration, and other losses.

Conceptual soil-water storage

$$\Delta S_{soil} = I - ET - Perc - Q_{sub},$$

where I is infiltration into the soil, ET is evapotranspiration, $Perc$ is deep percolation, and Q_{sub} is lateral subsurface outflow.

Factors increasing infiltration

- Permeable, well-structured soils.
- Vegetative cover and organic matter.
- Lower antecedent soil moisture.
- Longer contact time and surface storage.

Factors reducing infiltration

- Compaction, pavement, crusting, frozen soil.
- Saturated antecedent conditions.
- Very high rainfall intensity relative to infiltration capacity.

Exam linkage: infiltration affects curve number, runoff volume, water budget, erosion risk, and detention sizing.

4.1 Evaporation and Evapotranspiration

Evaporation is vapor loss from open water or wet surfaces; transpiration is water vapor loss through plants. Their combined effect is evapotranspiration (ET).

The FE handbook gives the pan-evaporation relation

$$E_L = P_c E_p,$$

where E_L is estimated lake evaporation, E_p is measured pan evaporation, and P_c is a pan coefficient. The FE handbook notes that P_c may vary substantially and gives a common representative value near 0.7.

Why $P_c < 1$ is common: evaporation pans respond differently from large lakes because of heat storage, geometry, advection, and boundary effects.

For a lake of area A_L , evaporation volume over a period is

$$V_E = E_L A_L.$$

Water-budget use. Convert ET or evaporation depth to the same basis as precipitation and storage. For a watershed budget stated in mm/year, all are naturally depth terms; for a reservoir volume budget, multiply depths by the relevant surface area.

5 Reservoir Storage and Continuity

The basic reservoir continuity equation is

$$\Delta S = I - O,$$

where I and O are inflow and outflow volumes over the same time interval. In rate form,

$$\frac{dS}{dt} = Q_{in} - Q_{out}.$$

For a discrete interval Δt ,

$$S_{j+1} = S_j + (\bar{Q}_{in} - \bar{Q}_{out})\Delta t.$$

Storage sizing concept

1. Choose a time step.
2. Convert inflow and outflow rates to interval volumes.
3. Compute incremental storage change.
4. Accumulate storage through time.
5. Required active storage is the difference between maximum and minimum cumulative storage over the design sequence, subject to the selected initial condition.

Flood detention: storage grows when inflow exceeds outflow. The reservoir hydrograph peak generally occurs near the time when inflow and outflow become equal and storage stops increasing.

5.1 Detention and Retention Basins

A **detention basin** temporarily stores stormwater and releases it at a controlled rate. A **retention basin** maintains permanent or long-term storage in addition to storm-control functions.

Primary hydraulic effect of detention

$$Q_{out,peak} < Q_{in,peak}$$

when sufficient storage and outlet control are provided. The outflow peak is typically delayed relative to the inflow peak.

Simple storage estimate. If inflow and allowed outflow are represented by idealized hydrographs, detention storage can be estimated as the maximum cumulative difference:

$$S_{req} = \max_t \left[\int_0^t (Q_{in} - Q_{out}) dt \right].$$

Detention vs. runoff volume: a conventional dry detention basin primarily changes timing and peak rate. Infiltration basins, bioretention, and retention systems may also reduce runoff volume through infiltration and ET.

Water-quality functions may include sediment settling, nutrient uptake, extended detention, infiltration, and reduced downstream erosion caused by peak-flow moderation.

5.2 Reservoir Routing

Reservoir routing tracks how a storage element transforms an inflow hydrograph into an outflow hydrograph. The essential equation is continuity:

$$\frac{dS}{dt} = I - O.$$

For a finite interval,

$$S_2 - S_1 \approx \left(\frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} \right) \Delta t.$$

A routing calculation also needs a relation between storage and outflow, often obtained from reservoir geometry and an outlet-control equation.

Qualitative results

- Greater storage generally produces stronger attenuation and more delay.
- A larger outlet capacity raises outflow and reduces required storage.
- At the time of maximum storage, $dS/dt = 0$, so $I = O$ in the continuous idealization.

FE approach: when a routing table is provided, apply continuity interval by interval. Do not assume outflow equals inflow except at specific instants or steady conditions.

5.3 Channel Routing Concepts

Channel routing represents movement of a hydrograph through a river or channel reach. Unlike a reservoir, a channel has distributed storage and travel time. Flood waves are translated downstream and often attenuated.

A common linear routing concept writes storage as a weighted function of inflow and outflow:

$$S = K [XI + (1 - X)O],$$

where K has dimensions of time and X is a weighting factor. If such coefficients are needed on the FE exam, they would normally be provided or embedded in a routing relation.

Physical interpretation

- K is related to travel time through the reach.
- Increasing reach storage tends to reduce the downstream peak.
- Flood-wave celerity and hydraulic conditions govern translation time.

Conceptual comparison: reservoir routing is dominated by level-pool storage; channel routing represents distributed storage and wave translation. Both satisfy continuity.

The FE specification explicitly lists both channel and reservoir routing, so expect conceptual or tabular continuity questions even when a detailed routing formula is not supplied in the handbook.

6 Erosion, Sediment, and Channel Stability

Erosion occurs when hydraulic forces exceed the resistance of soil or channel materials. Hydrology affects erosion by controlling runoff volume, peak discharge, duration, and flow velocity.

Key concepts

- **Detachment:** particles are separated from the bed or soil surface.
- **Transport:** detached particles are carried by runoff or streamflow.
- **Deposition:** particles settle when transport capacity decreases.

For a channel, boundary shear stress is often represented conceptually by

$$\tau_0 = \gamma R_h S,$$

where γ is specific weight of water, R_h is hydraulic radius, and S is energy slope. Stability requires resisting strength to exceed erosive hydraulic demand.

Hydrologic linkage: urbanization can increase the frequency and magnitude of erosive channel flows even when detention controls only a single design peak.

Control measures include vegetation, riprap, grade control, stabilized outlets, reduced drainage concentration, extended detention, and infiltration practices.

6.1 Stormwater Quality Management

Stormwater can transport sediment, nutrients, metals, hydrocarbons, pathogens, floatables, and oxygen-demanding materials. The pollutant load depends on both concentration and flow.

Mass loading

$$\dot{m} = CQ.$$

With concentration in mg/L and flow in MGD,

$$\dot{m}(\text{lb/day}) = C(\text{mg/L})Q(\text{MGD})(8.34).$$

For an event,

$$M = \int C(t)Q(t) dt.$$

If an event mean concentration C_{EMC} is supplied,

$$M \approx C_{EMC}V_r.$$

Management objectives: reduce runoff volume, reduce peak flow, remove pollutants, protect receiving-stream stability, and mimic predevelopment hydrology where practical.

Common practices include detention/retention basins, vegetated swales, bioretention, infiltration systems, constructed wetlands, filtration, source control, and street sweeping. Selection depends on site soils, groundwater constraints, pollutant type, and design objectives.

6.2 Wetlands in Surface-Water Systems

Wetlands interact with surface water through storage, evapotranspiration, sedimentation, vegetation, and biogeochemical transformations. Constructed wetlands are also used for stormwater and wastewater polishing.

Hydrologic functions

- Temporary storage and attenuation of flows.
- Reduced flow velocity and enhanced sedimentation.
- Increased hydraulic residence time.
- Exchange with shallow groundwater depending on site conditions.

Water-quality mechanisms

- Settling of suspended solids.
- Plant uptake and microbial transformation of nutrients.
- Sorption to soils and organic matter.
- Aerobic and anaerobic reactions in different microzones.

A simple hydraulic residence time estimate is

$$\theta = \frac{V}{Q}.$$

Exam concept: increasing residence time can improve settling and reaction opportunity, but actual treatment depends on hydraulics, short-circuiting, vegetation, temperature, and pollutant properties.

6.3 Eutrophication and Lake Productivity

Eutrophication is nutrient enrichment of a water body, commonly associated with increased primary productivity and potential dissolved-oxygen problems. Phosphorus is often an important limiting nutrient in freshwater systems, although nutrient limitation varies by system.

The FE handbook includes a lake-classification table using indicators such as chlorophyll *a*, Secchi depth, and total phosphorus to distinguish oligotrophic, mesotrophic, and eutrophic conditions.

General progression

- **Oligotrophic:** low productivity, clearer water, lower nutrient levels.
- **Mesotrophic:** intermediate productivity.
- **Eutrophic:** high productivity, often higher algal biomass and lower transparency.

Mechanism: nutrient addition → algal/plant production → organic-matter decay → oxygen consumption. Stratification can intensify low-DO conditions in bottom waters.

Possible management measures include nutrient-source reduction, erosion control, improved wastewater nutrient removal, stormwater controls, and watershed best-management practices.

7 Dissolved Oxygen and BOD in Streams

Dissolved oxygen (DO) is a key surface-water quality indicator. Oxygen-consuming organic matter is commonly represented by biochemical oxygen demand (BOD).

For first-order BOD exertion,

$$BOD_t = L_0 (1 - e^{-kt}),$$

where L_0 is ultimate BOD and k is a base- e decay constant.

Remaining ultimate BOD is

$$L(t) = L_0 e^{-kt}.$$

Define DO deficit as

$$D = DO_{sat} - DO.$$

A larger deficit means lower actual DO relative to saturation.

Competing processes: deoxygenation from BOD increases D ; atmospheric reaeration decreases D . Their competition creates the classic DO-sag curve.

Temperature matters. The FE handbook provides temperature correction in the form

$$k_T = k_{20} \theta^{T-20}.$$

For reaeration, the handbook lists $\theta \approx 1.024$.

7.1 Streeter-Phelps Dissolved-Oxygen Sag

For a stream receiving biodegradable waste, the FE handbook gives the Streeter-Phelps deficit relation

$$D(t) = \frac{k_d L_0}{k_r - k_d} (e^{-k_d t} - e^{-k_r t}) + D_0 e^{-k_r t},$$

where k_d is deoxygenation rate, k_r is reaeration rate, L_0 is initial ultimate BOD after mixing, and D_0 is initial DO deficit. Actual DO is

$$DO(t) = DO_{sat} - D(t).$$

The critical time for maximum deficit is

$$t_c = \frac{1}{k_r - k_d} \ln \left[\frac{k_r}{k_d} \left(1 - \frac{D_0(k_r - k_d)}{k_d L_0} \right) \right].$$

Critical point: minimum DO occurs where the deficit is maximum. Convert travel time to downstream distance with $x = ut$ using consistent time units.

Unit trap: if u is in m/s and t is in days, multiply time by 86,400 s/day before computing distance.

7.2 Mixing and Initial Conditions for Stream Modeling

When two steady flows mix completely and the constituent is conservative over the short mixing zone, use a flow-weighted mass balance:

$$C_m = \frac{Q_1 C_1 + Q_2 C_2}{Q_1 + Q_2}.$$

The same form applies to initial BOD after mixing if decay during mixing is neglected.

For DO, mix DO concentrations first:

$$DO_m = \frac{Q_1 DO_1 + Q_2 DO_2}{Q_1 + Q_2}.$$

Then calculate the initial deficit

$$D_0 = DO_{sat} - DO_m.$$

Sequence for Streeter-Phelps problems

1. Mix flows and concentrations.
2. Determine L_0 and D_0 after mixing.
3. Apply temperature corrections if required.
4. Compute $D(t)$ or critical time.
5. Convert deficit back to DO.

Avoid averaging concentrations without flow weighting unless the two flows are equal.

7.3 Temperature Effects on Surface-Water Quality

Temperature affects both reaction kinetics and oxygen solubility. As water temperature rises, biochemical reaction rates generally increase while DO saturation concentration generally decreases.

The FE handbook temperature-correction form is

$$k_T = k_{20}\theta^{T-20}.$$

For reaeration it provides $\theta = 1.024$.

Implications

- Higher temperature can increase deoxygenation rate.
- Higher temperature often reduces DO_{sat} .
- Both effects can make warm-water low-DO conditions more critical.

DO-table use: the FE handbook includes dissolved-oxygen saturation data as a function of temperature and salinity. Use the table value corresponding to the problem conditions rather than assuming a universal saturation concentration.

Temperature correction example

$$k_{25} = k_{20}(1.024)^5$$

for a reaeration constant adjusted from 20°C to 25°C.

7.4 Surface-Water Quality Mass Balances

For a completely mixed water body with volume V , concentration C , inflow Q_{in} at concentration C_{in} , and outflow Q_{out} , a generic mass balance is

$$\frac{d(CV)}{dt} = Q_{in}C_{in} - Q_{out}C + rV.$$

For constant V and first-order decay $r = -kC$,

$$V \frac{dC}{dt} = Q(C_{in} - C) - kCV$$

when inflow and outflow are equal to Q .

At steady state,

$$0 = Q(C_{in} - C) - kCV,$$

so

$$C = \frac{QC_{in}}{Q + kV}.$$

Hydraulic residence time

$$\theta = \frac{V}{Q}, \quad C = \frac{C_{in}}{1 + k\theta}$$

for this idealized steady completely mixed first-order system.

Although detailed reactor modeling also appears elsewhere in the FE Environmental specification, these mass-balance ideas are directly useful for lakes, ponds, wetlands, and detention systems.

8 Runoff Control and Low-Impact Management

Runoff management can target four distinct outcomes: reduce runoff volume, reduce peak discharge, improve water quality, and protect channel stability.

Typical control categories

- **Source control:** minimize connected impervious area, pollutant prevention.
- **Infiltration:** infiltration basins, permeable pavement, bioretention where site conditions permit.
- **Conveyance:** vegetated swales and level spreaders that slow and distribute flow.
- **Storage:** detention/retention basins and constructed wetlands.

Hydrologic effect hierarchy

- Infiltration practices can reduce both runoff volume and peak.
- Detention primarily reduces and delays peak flow.
- Treatment practices may reduce pollutant concentration without materially changing runoff volume.

Sizing logic. Peak-flow controls often use Rational Method or design hydrographs; volume controls often use rainfall depth, curve-number runoff, or water-quality volume approaches provided in the problem statement.

9 Integrated FE Problem-Solving Workflow

Step 1: classify the problem.

- Peak runoff → Rational Method.
- Runoff depth/volume → NRCS/SCS.
- Probability → return-period formula.
- Storage/routing → continuity.
- Stream DO → mixing + Streeter–Phelps.
- Long-term watershed accounting → water budget.

Step 2: choose a unit basis. Convert areas, depths, flow rates, and time intervals before arithmetic.

Step 3: state assumptions. Examples: complete mixing, steady flow, constant intensity, supplied C or CN , no reaction in mixing zone.

Step 4: perform a magnitude check.

- $0 < C < 1$.
- $0 < CN \leq 100$.
- $0 \leq Q_r \leq P$.
- $DO = DO_{sat} - D$.
- Storage rises only when inflow exceeds outflow.

FE search strategy: know where the handbook formulas live. Hydrology/water-resources material is grouped in the Civil Engineering portion, while BOD and Streeter–Phelps appear in Environmental Engineering.

9.1 Formula Sheet and Last-Minute Review

Rational Method

$$Q_p = CIA$$

$$C_m = \frac{\sum Q_i C_i}{\sum Q_i}$$

NRCS/SCS

$$S = \frac{1000}{CN} - 10, \quad Q_r = \frac{(P - 0.2S)^2}{P + 0.8S}$$

Composite parameter

$$X_{comp} = \frac{\sum X_i A_i}{A_T}$$

Hydrologic budget

$$P + Q_{in} - Q_{out} + Q_g - E - T - I = \Delta S$$

Pan evaporation

$$E_L = P_c E_p$$

Return-period risk

$$P_{\geq 1} = 1 - \left(1 - \frac{1}{T}\right)^n$$

Reservoir continuity

$$\frac{dS}{dt} = I - O$$

Unit hydrograph peak

$$q_p = \frac{484AQ_r}{T_p}$$

Mixing concentration

BOD kinetics

$$L(t) = L_0 e^{-kt}$$

DO deficit

$$D = DO_{sat} - DO$$

Streeter-Phelps

$$D(t) = \frac{k_d L_0}{k_r - k_d} (e^{-k_d t} - e^{-k_r t}) + D_0 e^{-k_r t}$$

Temperature correction

$$k_T = k_{20} \theta^{T-20}$$

Event load

$$M = C_{EMC} V_r$$

Residence time

$$\theta = \frac{V}{Q}$$

Final traps: distinguish intensity from depth; distinguish peak flow from volume; convert days to seconds for distance; area-weight coefficients; use the complement for multi-year risk; and apply continuity using volumes over a common interval.

10 20 Example Problems

The following original practice problems are designed to match the calculation style and scope of the FE Environmental Surface Water Resources and Hydrology domain. Numerical data are illustrative.

Example Problem 1: Composite Rational-Method Peak Flow

A 60-acre watershed is 40% commercial with $C = 0.85$ and 60% residential with $C = 0.45$. The design rainfall intensity is 3.0 in./hr. Find peak runoff.

Solution

$$C_{comp} = 0.40(0.85) + 0.60(0.45) = 0.61.$$

$$Q_p = CIA = (0.61)(3.0)(60) = 109.8 \text{ cfs.}$$

Answer. (approximately).

Example Problem 2: Return-Period Risk

What is the probability that a 50-year event is equaled or exceeded at least once during a 20-year project life?

Solution

$$P_{\geq 1} = 1 - \left(1 - \frac{1}{50}\right)^{20} = 1 - (0.98)^{20} = 0.332.$$

Answer. .

Example Problem 3: NRCS/SCS Runoff Depth

A watershed has $CN = 80$ and receives 4.0 in. of rainfall. Determine direct runoff depth.

Solution

$$S = \frac{1000}{80} - 10 = 2.50 \text{ in.}, \quad 0.2S = 0.50 \text{ in.}$$

$$Q_r = \frac{(4.0 - 0.50)^2}{4.0 + 0.8(2.50)} = \frac{12.25}{6.00} = 2.042 \text{ in.}$$

Answer. .

Example Problem 4: Runoff Volume from Curve Number

Using Problem 3, if the watershed area is 120 acres, find runoff volume in acre-ft.

Solution

$$V = \frac{2.042}{12}(120) = 20.42 \text{ acre-ft.}$$

Answer. .

Example Problem 5: Composite Curve Number

A 100-acre basin contains 35 acres at $CN = 92$, 45 acres at $CN = 78$, and 20 acres at $CN = 65$. Find the composite curve number.

Solution

$$CN_c = \frac{35(92) + 45(78) + 20(65)}{100} = 80.3.$$

Answer. $CN \approx 80$.

Example Problem 6: Rainfall Depth from Intensity

A storm has an average intensity of 2.4 in./hr for 45 min. Find rainfall depth.

Solution

$$t = 45/60 = 0.75 \text{ hr}, \quad P = it = (2.4)(0.75) = 1.80 \text{ in.}$$

Answer. 1.80 in.

Example Problem 7: Water-Budget Storage Change

Over one month, a lake receives 3.2 in. precipitation and 1.1 in. equivalent surface inflow. Losses are 2.4 in. evaporation, 0.6 in. infiltration, and 0.5 in. surface outflow. Ignore groundwater and transpiration. Find storage change as equivalent depth.

Solution

$$\Delta S = 3.2 + 1.1 - 2.4 - 0.6 - 0.5 = 0.8 \text{ in.}$$

Answer. (storage increases).

Example Problem 8: Pan Evaporation

A Class A pan records 8.5 in. evaporation over a period. If $P_c = 0.70$, estimate lake evaporation.

Solution

$$E_L = P_c E_p = (0.70)(8.5) = 5.95 \text{ in.}$$

Answer. .

Example Problem 9: Reservoir Storage Increment

During a 2-hour interval, average reservoir inflow is 900 cfs and average outflow is 500 cfs. Find the increase in storage.

Solution

$$\Delta S = (900 - 500)(2 \times 3600) = 2.88 \times 10^6 \text{ ft}^3.$$

In acre-ft,

$$\Delta S = \frac{2.88 \times 10^6}{43,560} = 66.1 \text{ acre-ft.}$$

Answer. 66.1 acre-ft increase.

Example Problem 10: Triangular Hydrograph Volume

A triangular direct-runoff hydrograph has a peak of 240 cfs and a base duration of 10 hr. Find runoff volume in acre-ft.

Solution

$$V = \frac{1}{2}(240)(10 \times 3600) = 4.32 \times 10^6 \text{ ft}^3.$$

$$V = 4.32 \times 10^6 / 43,560 = 99.2 \text{ acre-ft.}$$

Answer. 99.2 acre-ft.

Example Problem 11: Unit-Hydrograph Peak

A 12-mi² watershed produces 1.5 in. direct runoff. The triangular hydrograph reaches its peak 4.0 hr after runoff begins. Estimate peak discharge using the FE handbook relation.

Solution

$$q_p = \frac{484AQ_r}{T_p} = \frac{484(12)(1.5)}{4} = 2178 \text{ cfs.}$$

Answer. $2.18 \times 10^3 \text{ cfs}$.

Example Problem 12: Event Pollutant Load

Storm runoff volume is $3.0 \times 10^6 \text{ L}$ and event mean TSS concentration is 80 mg/L. Find TSS mass in kg.

Solution

$$M = CV = (80 \text{ mg/L})(3.0 \times 10^6 \text{ L}) = 2.4 \times 10^8 \text{ mg.}$$

$$M = 240 \text{ kg.}$$

Answer. 240 kg TSS .

Example Problem 13: Flow-Weighted Stream Mixing

A stream carries 8.0 m³/s at 9.0 mg/L DO. An effluent enters at 2.0 m³/s and 4.0 mg/L DO. Assume instantaneous complete mixing. Find mixed DO.

Solution

$$DO_m = \frac{8(9) + 2(4)}{8 + 2} = 8.0 \text{ mg/L.}$$

Answer. 8.0 mg/L.

Example Problem 14: Initial DO Deficit

Using Problem 13, if saturation DO is 9.5 mg/L, find the initial deficit.

Solution

$$D_0 = DO_{sat} - DO_m = 9.5 - 8.0 = 1.5 \text{ mg/L.}$$

Answer. 1.5 mg/L.

Example Problem 15: BOD Remaining After Travel

Ultimate BOD after mixing is $L_0 = 24$ mg/L and $k_d = 0.25$ day⁻¹. Find remaining ultimate BOD after 2 days.

Solution

$$L(2) = 24e^{-0.25(2)} = 24e^{-0.5} = 14.56 \text{ mg/L.}$$

Answer. 14.6 mg/L.

Example Problem 16: Temperature-Corrected Reaeration Constant

At 20°C, $k_{r,20} = 0.60$ day⁻¹. Estimate k_r at 25°C using $\theta = 1.024$.

Solution

$$k_{r,25} = 0.60(1.024)^5 = 0.675 \text{ day}^{-1}.$$

Answer. 0.675 day⁻¹.

Example Problem 17: Streeter-Phelps Deficit at One Day

For a mixed stream, $L_0 = 20$ mg/L, $D_0 = 1.0$ mg/L, $k_d = 0.20$ day⁻¹, and $k_r = 0.50$ day⁻¹. Find $D(1)$.

Solution

$$D(1) = \frac{(0.20)(20)}{0.50 - 0.20} (e^{-0.20} - e^{-0.50}) + 1.0e^{-0.50}.$$

$$D(1) = 13.333(0.8187 - 0.6065) + 0.6065 = 3.436 \text{ mg/L}.$$

Answer. 3.44 mg/L deficit.

Example Problem 18: DO from Deficit

Using Problem 17, if $DO_{sat} = 9.0$ mg/L, find DO after one day.

Solution

$$DO = DO_{sat} - D = 9.0 - 3.436 = 5.564 \text{ mg/L}.$$

Answer. 5.56 mg/L.

Example Problem 19: Critical Distance from Travel Time

A DO-sag calculation gives a critical time of 1.8 days. Stream velocity is 0.35 m/s. Find critical distance downstream in km.

Solution

$$t = (1.8)(86,400) = 155,520 \text{ s.}$$

$$x = ut = (0.35)(155,520) = 54,432 \text{ m} = 54.4 \text{ km.}$$

Answer. 54.4 km.

Example Problem 20: Storage Required from a Simple Inflow-Outflow Sequence

A detention basin is analyzed in three 1-hour intervals. Average inflows are 100, 300, and 150 cfs; average controlled outflows are 80, 120, and 140 cfs. Starting with zero incremental storage, estimate the maximum storage accumulated.

Solution. For each hour,

$$\Delta S = (Q_{in} - Q_{out})(3600).$$

Interval changes are

$$72,000, \quad 648,000, \quad 36,000 \text{ ft}^3.$$

Cumulative storage is

$$72,000, \quad 720,000, \quad 756,000 \text{ ft}^3.$$

$$S_{max} = 756,000/43,560 = 17.36 \text{ acre-ft.}$$

Answer. 17.4 acre-ft.

Reference Alignment

This study guide was developed to match the published scope of the NCEES FE Environmental CBT exam and the equations and reference topics contained in the FE Reference Handbook 10.6. The FE Environmental specification identifies Surface Water Resources and Hydrology as a 9–14 question domain covering runoff calculations, water storage sizing, routing, water quality/modeling, and water budget. The FE Reference Handbook includes hydrology/water-resources formulas for NRCS/SCS runoff, Rational Method, hydrologic mass balance, pan evaporation, unit hydrographs, runoff coefficients, return-period probability, and related water-quality formulas including BOD and Streeter–Phelps.

Copyright note: This guide provides original explanations and practice problems and does not reproduce NCEES handbook pages or copyrighted tables. Examinees should practice searching the official FE Reference Handbook used for their exam administration.

Suggested Study Use

1. Read the 30-page study section once for structure.
2. Rework the formula sheet from memory.
3. Solve the 20 problems without looking at the solutions.
4. Repeat missed problem types under a 3-minute-per-question target.
5. Practice handbook keyword searches such as “hydrologic”, “SCS”, “unit hydrograph”, “return period”, “Streeter”, and “dissolved oxygen”.