PE CIVIL: WATER RESOURCES AND ENVIRONMENTAL SOLUTIONS

Detailed solutions for each question begin on the next page. Unless otherwise noted, questions can be solved using common engineering knowledge or the NCEES *PE Civil Reference Handbook.*

1	D	**21**	A	**41**	see solution	**61**	A
2	C	**22**	A	**42**	B	**62**	C
3	C	**23**	C	**43**	B	**63**	C
4	D	**24**	B	**44**	C	**64**	C
5	C	**25**	C	**45**	C	**65**	D
6	B	**26**	B	**46**	B	**66**	C
7	C	**27**	C	**47**	B	**67**	C
8	D	**28**	B	**48**	D	**68**	B
9	B	**29**	D	**49**	B	**69**	D
10	B	**30**	D	**50**	A	**70**	B
11	A	**31**	C	**51**	C	**71**	D
12	A	**32**	D	**52**	A	**72**	C
13	C	**33**	A	**53**	C	**73**	C
14	D	**34**	C	**54**	see solution	**74**	B, E
15	B	**35**	B	**55**	C	**75**	A
16	D	**36**	C	**56**	B	**76**	see solution
17	C	**37**	B	**57**	C	**77**	B
18	D	**38**	D	**58**	B	**78**	C
19	A	**39**	C	**59**	A	**79**	C
20	C	**40**	C	**60**	C	**80**	A

1. Horizontal length of side slope $= 14 \times \frac{3}{2} = 21.0 \text{ ft}$

Slope length $= \sqrt{(14)^2 + (21)^2} = 25.24 \text{ ft}$

Cross-sectional area of lining $= \left[(2 \times 25.24) + 9\right]\frac{7}{12} = 34.70 \text{ ft}^2$

Volume of lining $= \frac{(34.70 \times 227)}{27} = 291.7 \text{ yd}^3$

Delivered volume $= 291.7 \text{ yd}^3 \times \underset{\text{(waste)}}{1.12} = 327 \text{ yd}^3$

THE CORRECT ANSWER IS: D

2. $D = \frac{\$75,000 - \$10,000}{10}$

$D = \$6,500$

Book value after 8 years $= \$75,000 - (8)(\$6,500) = \$23,000$

THE CORRECT ANSWER IS: C

3. Crew cost = 2($50/hr) = $100/hr

Days allowed $= \frac{\$4,000}{(8 \text{ hr/day})(\$100/\text{hr})} = 5 \text{ days}$

THE CORRECT ANSWER IS: C

4. Activities: (7) + (4) + (5)

Days: 30 + 10 + 10 = 50 days

THE CORRECT ANSWER IS: D

5. $1{,}000 \text{ kN} = 1{,}000 \text{ kN} \times \frac{1 \text{ ton}}{8.896444 \text{ kN}} = 112.4 \text{ tons}$

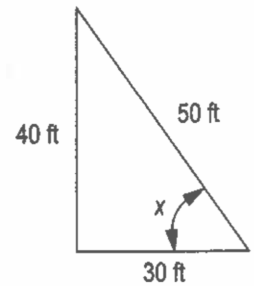
150 tons > 112.4 tons

THE CORRECT ANSWER IS: C

6. $\tan(x) = \frac{40}{30} \quad x = 53.13°$

$\cos(53.13°) \times 100 \text{ ft} = 60 \text{ ft}$

$60 \text{ ft} - 35 \text{ ft} = 25 \text{ ft}$



THE CORRECT ANSWER IS: B

7. $w = (20 \text{ lb/ft}^2)(8 \text{ ft}) = 160 \text{ lb/vertical ft per brace location}$

$\sum M_a = 0$

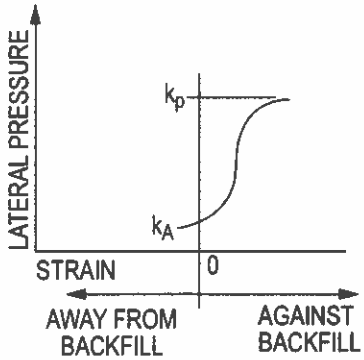
$\sum M_a = (160 \text{ lb/ft})(16 \text{ ft})(16 \text{ ft}/2) - 10 \text{ ft}\,(R_x) = 0$

$R_x = 2{,}048 \text{ lb}$

$\text{Axial load in brace} = \frac{(2{,}048)\sqrt{2}}{1} = 2{,}896 \text{ lb}$

THE CORRECT ANSWER IS: C

8. The wall translation (or strain) required to achieve the passive state is at least twice that required to reach the active state.



THE CORRECT ANSWER IS: D

9. The solution is based on the knowledge that consolidation settlement is the result of the expulsion of pore water from saturated soil due to imposed load. Therefore, the volume of the wick drain effluent (water) to be treated equals the consolidation settlement volume over the affected site area, and is computed as follows:

Affected area = 21.5 acres × 43,560 ft^2/acre = 936,540 ft^2

Mean consolidation settlement over affected area = 22 in. = 1.83 ft

Settlement volume = effluent volume = 936,540 ft^2 × 1.83 = 1,713,868 ft^3

Convert to gal: 1,713,868 ft^3 × 7.48 gal/ft^3 = 12,819,733 gal

Cost for effluent treatment and disposal = 12,819,733 gal × \$0.25/gal = \$3,204,934

THE CORRECT ANSWER IS: B

10. Effective vertical stress at Point A, σ'_v

$$= 10 \text{ ft} \times 120 \text{ pcf} + 5 \text{ ft}(120 \text{ pcf} - 62.4 \text{ pcf}) + 7 \text{ ft}(110 \text{ pcf} - 62.4 \text{ pcf})$$
$$= 1{,}200 \text{ psf} + 288 \text{ psf} + 333 \text{ psf}$$
$$= 1{,}821 \text{ psf}$$

THE CORRECT ANSWER IS: B

11. The ultimate bearing capacity would be based on buoyant unit weight, also referred to as the effective unit weight.

Effective unit weight = saturated unit weight – unit weight of water

THE CORRECT ANSWER IS: A

12. The long-term settlement for Case I is less than Case II because clay is subject to long-term settlement.

THE CORRECT ANSWER IS: A

13. The minimum factor of safety for permanent slopes is 1.5. Other references use a factor of safety greater than or equal to 1.3, but of the options presented, 1.5 is the closest.

THE CORRECT ANSWER IS: C

14. Because the structure is cantilevered, in addition to the wind, dead load and live load will contribute to uplift.

THE CORRECT ANSWER IS: D

15. By inspection, Member b = 0 kips, and Member c = 100 kips.

THE CORRECT ANSWER IS: B

16. Beam stress, $f = M/S$, where $M = wL^2/8$ and $S = bh^2/6$.
S is equal for both beams, but M varies because it depends on beam length.

Beam 1 (shorter beam): $M_1 = wL^2/8$

Beam 2 (longer beam): $M_2 = w(2L)^2/8 = 4wL^2/8$

M_2 is four times greater than M_1. Therefore, the maximum bending stress is four times greater in the longer beam.

THE CORRECT ANSWER IS: D

17. Uniform load: $V = \frac{wL}{2} = \frac{1(30)}{2} = \frac{30 \text{ kips}}{2} = 15 \text{ kips}$

Point load: $V = \frac{P}{2} = 15 \text{ kips}$

$P = 2(15) = 30 \text{ kips}$

THE CORRECT ANSWER IS: C

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THE CORRECT ANSWER IS: C

18. I_x is maximum for this section by inspection, or calculate $I_x \approx \Sigma A d^2$ for each section.

THE CORRECT ANSWER IS: D

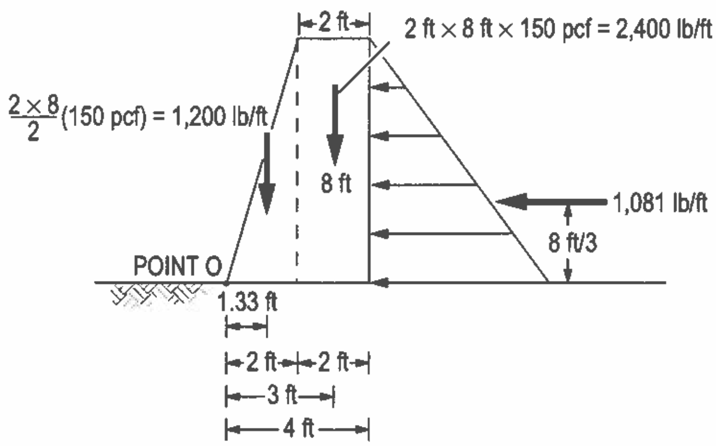
19. $\phi = 32°$ $\quad K_a = \tan^2(45 - \phi/2) = 0.307$

$\gamma_t = 110 \text{ pcf} \quad P_a = (0.5)(110)(8)^2(0.307) = 1{,}081 \text{ lb/ft}$

$M_a = (1{,}081)(8/3) = 2{,}883 \text{ ft-lb/ft}$

$$\left.\begin{array}{l}(2)(8)(150)(1)(3) = 7{,}200 \text{ ft-lb/ft} \\ (1/2)(2)(8)(150)(1)(2)(2/3) = 1{,}600 \text{ ft-lb/ft}\end{array}\right\} \text{ total} = 8{,}800 \text{ ft-lb/ft}$$

$SF = 8{,}800/2{,}883 = 3.05$



THE CORRECT ANSWER IS: A

20. $$Q = VA = \left\{\frac{1.49}{n} R^{2/3} S^{1/2}\right\} A$$

$$= \left\{\frac{1.49}{0.022}\left[\frac{(1.5 \text{ ft} \times 4 \text{ ft})}{4 \text{ ft} + 2(1.5 \text{ ft})}\right]^{2/3} (0.002)^{1/2}\right\}(1.5 \text{ ft} \times 4 \text{ ft})$$

$$= 16.4 \text{ cfs}$$

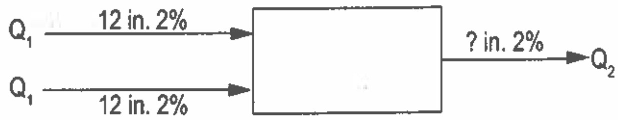
$$\text{Volume} = 25 \text{ acre-ft} \times \frac{43{,}560 \text{ ft}^3}{1 \text{ acre-ft}} = 1.089 \times 10^6 \text{ ft}^3$$

$$\text{Time} = \frac{1.089 \times 10^6 \text{ ft}^3}{16.4 \text{ ft}^3/\text{sec}} \times \frac{1 \text{ min}}{60 \text{ sec}} \times \frac{1 \text{ hr}}{60 \text{ min}}$$

$$= 18.5 \text{ hours}$$

THE CORRECT ANSWER IS: C

21.



$$2[V_1A_1]=[V_2A_2]$$

$$2\left[\left(\frac{1.49}{n}\right)(A_1)R_1^{2/3}S^{1/2}\right]=\left[\left(\frac{1.49}{n}\right)(A_2)R_2^{2/3}S^{1/2}\right]$$

$$2\left[(A_1)\left(\frac{A_1}{P_1}\right)^{2/3}\right]=\left[(A_2)\left(\frac{A_2}{P_2}\right)^{2/3}\right]$$

$$A_1=\frac{\pi D^2}{4}=\frac{\pi(1)^2}{4}=0.785\text{ ft}^2$$

$$P_1=\pi(D)=\pi(1)=3.14\text{ ft}$$

$$2\left[(0.785)\left(\frac{0.785}{3.14}\right)^{2/3}\right]=\left[\left(\frac{\pi D_2^2}{4}\right)\left(\frac{\frac{\pi(D_2)^2}{4}}{(\pi D_2)}\right)^{2/3}\right]$$

$$0.623 \quad =\left(\frac{\pi D_2^2}{4}\right)\left(\frac{D_2}{4}\right)^{2/3}$$

$$=\pi\left(\frac{D_2^2}{4}\right)\left(\frac{D_2}{4}\right)^{2/3}$$

$$=\pi(D_2)^{8/3}\left(\frac{1}{4}\right)\left(\frac{1}{4}\right)^{2/3}$$

$$0.623=0.311(D_2)^{8/3}$$

$$\left(\frac{0.623}{0.311}\right)^{3/8}=D_2$$

$$D_2=1.297\text{ ft}\times\frac{12\text{ in.}}{\text{ft}}=15.6\text{ in.}\approx 16\text{ in.}$$

THE CORRECT ANSWER IS: A

22. According to the arithmetic mean method, the average precipitation is simply the average of all the rainfall gauges.

Average precipitation = (2.1 + 3.6 + 1.3 + 1.5 + 2.6 + 6.1 + 5.1 + 4.8 + 4.1 + 2.8 + 3.0)/11
= 3.4 in.

THE CORRECT ANSWER IS: A

23. From the IDF curve, read a rainfall intensity of 3.5 in./hr for a 50-year frequency rainfall with a 60-min duration.

From the table, the runoff coefficient for a downtown area is 0.70–0.95. For the maximum runoff rate, use the high value of 0.95.

$Q = CiA = 0.95 \times 3.5 \text{ in./hr} \times 90 \text{ ac}$

$Q = 300 \text{ cfs}$

THE CORRECT ANSWER IS: C

24. $$\text{Time} = \frac{V}{Q}$$

$$V = 400{,}000 \text{ gal} \times \frac{\text{ft}^3}{7.48 \text{ gal}} = 53{,}476 \text{ ft}^3$$

$$Q = 1.5 \text{ ft}^3/\text{sec}$$

$$\text{Time} = \frac{53{,}476 \text{ ft}^3}{1.5 \text{ ft}^3/\text{sec}} \times \frac{1 \text{ hr}}{3{,}600 \text{ sec}} = 9.9 \text{ hours}$$

THE CORRECT ANSWER IS: B

25. The Darcy–Weisbach equation is $h_f = f\frac{L}{D}\frac{V^2}{2g}$

where

h_f = headloss, ft
f = friction factor, unitless
L = length, ft
D = diameter of pipe, ft
V = velocity, ft/sec
g = gravitational constant, 32.2 ft/sec^2

Substituting gives

$$5 \text{ ft} = 0.0115 \times \frac{1{,}650 \text{ ft}}{3.0 \text{ ft}} \times \frac{V^2}{2 \times 32.2 \text{ ft/sec}^2}$$

$$V^2 = 50.91 \text{ ft}^2/\text{sec}^2$$

$$V = 7.135 \text{ ft/sec}$$

$$Q = VA = V \times \frac{\pi}{4}D^2 = 7.135 \text{ ft/sec} \times \frac{\pi}{4}(3.0 \text{ ft})^2$$

$$Q = 50 \text{ cfs}$$

THE CORRECT ANSWER IS: C

26. $$z_1 + \frac{P_1}{\gamma} + \frac{v_1^2}{2g} = z_2 + \frac{P_2}{\gamma} + \frac{v_2^2}{2g}$$

$z_1 = z_2$

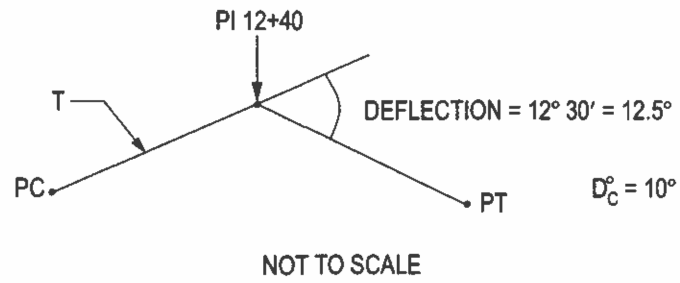
Since $A_1 > A_2$, $v_1 < v_2$.

$$\therefore \frac{v_1^2}{2g} < \frac{v_2^2}{2g}$$

so $P_1 > P_2$ to balance

THE CORRECT ANSWER IS: B

27.



$$R = 5{,}729.648/D_C^\circ$$
$$= 5{,}729.648/10 = 572.96 \text{ ft}$$
$$T = R \tan\left(\frac{1}{2}\Delta\right) = R \tan(6.25°)$$
$$= 572.96 (\tan 6.25°)$$
$$= 572.96 (0.1095178)$$
$$= 62.75 \text{ ft}$$

$$\text{Station PC} = \text{Station PI} - T$$
$$= (12+40) - 62.75$$
$$= 11 + 77.25$$

$$\text{Station PT} = \text{Station PC} + \text{length of curve}$$

$$\text{Length of curve} = L = 100\,\Delta/D_C^\circ$$
$$= 100(12.5)/10 = 125 \text{ ft}$$

$$\text{Station PT} = \text{Station PC} + 125 \text{ ft} = (11+77.25) + 125 = 13 + 02.25$$

THE CORRECT ANSWER IS: C

28. $L = KA$

$K = L/A$

L = length of vertical curve, ft

A = algebraic difference in grades, percent $(g_2 - g_1)$

Given: VPC = 12+00

VPI = 13+50

VPT = 15+00

$g_1 = -2.30\%$

$g_2 = +3.00\%$

$L = 300$ ft

$$K = \frac{L}{A} = \frac{300}{3-(-2.3)} = 56.60 \text{ ft/percent for the vertical curve.}$$

The length from Station 14+00 to Station 15+00 = 100 ft

$$K = \frac{L}{A}$$

$$A = \frac{L}{K} = \frac{100}{56.60} = 1.77\%$$

$$A = g_2 - g_1$$

Tangent slope at Station 14+00 = g_1

$$g_1 = g_2 - A = 3.00\% - 1.77\% = 1.23\%$$

Alternate solution:

Y = elevation at a point X ft from VPC

Y' = slope at a point X ft from VPC

$X = [14+00] - [12+00] = 200$ ft

g_1 = slope 1 in ft/ft

g_2 = slope 2 in ft/ft

L = length of vertical curve, ft

$$Y = Y_{VPC} + g_1 X + \left(\frac{g_2 - g_1}{2L}\right) X^2$$

$$Y' = g_1 + \left(\frac{g_2 - g_1}{L}\right) X$$

$$Y' = -0.023 + \left(\frac{0.03-(-0.023)}{300}\right) 200 = 0.0123 \text{ ft/ft or } 1.23\%$$

THE CORRECT ANSWER IS: B

29. $$\text{AADT} = \frac{\Sigma(\text{Jan. through Dec.})}{12}$$

$$= 833{,}200/12 = 69{,}433$$

$$\Sigma(\text{June through Aug.}) = 77{,}300$$

$$78{,}950$$

$$\underline{77{,}200}$$

$$233{,}450/3 = 77{,}817$$

Seasonal factor for June through August

$$= 77{,}817/69{,}433$$

$$= 1.121$$

THE CORRECT ANSWER IS: D

30. The commonly used soil classification systems for engineering applications are USCS and AASHTO. Both of these systems use gradation and Atterberg limits as two of the criteria.

THE CORRECT ANSWER IS: D

31. The Standard Penetration Test (SPT) N-value provides an indication of the relative density of cohesionless soils.

THE CORRECT ANSWER IS: C

32. An early-strength concrete is needed with a minimum compressive strength of 3,500 psi. To achieve the requirements, a Type III cement and chemical accelerators would be necessary.

THE CORRECT ANSWER IS: D

33. **THE CORRECT ANSWER IS: A**

34. Area = $\pi d^2/4 = 28.3\ \text{in}^2$

Compressive stress = axial load/area

Sample 1 $f'_c = \dfrac{65{,}447}{28.3} = 2{,}313$ psi

Sample 2 $f'_c = \dfrac{63{,}617}{28.3} = 2{,}248$ psi

Sample 3 $f'_c = \dfrac{69{,}872}{28.3} = 2{,}469$ psi

Average $= \dfrac{(2{,}313 + 2{,}248 + 2{,}469)}{3} = 2{,}343$ psi

THE CORRECT ANSWER IS: C

35. Total density $(\gamma) = \dfrac{W}{V} = \dfrac{W_s + W_w}{V_s + V_w + V_a}$

where γ = total density

W = total weight

V = total volume

W_s = weight soil

W_w = weight of water

V_s = volume of soil

V_w = volume of water

V_a = volume of air

$$\gamma = \frac{9.11\ \text{lb} - 4.41\ \text{lb}}{0.03\ \text{ft}^3} = 156.67\ \text{lb/ft}^3\ (\text{pcf})$$

Dry unit weight of soil $(\gamma_d) = \dfrac{\gamma}{1 + w}$

where w = moisture content

$$\gamma_d = \frac{156.67\ \text{pcf}}{1 + 0.115} = 140.51\ \text{pcf}$$

THE CORRECT ANSWER IS: B

36. Use Average End Area Method.

Stationing	Excavation (yd³)	Embankment (yd³)
1+00 to 2+00	$\frac{50+150}{2} \times \frac{100}{27} = 370$	
2+00 to 3+00	$\frac{50+0}{2} \times \frac{100}{27} = 93$	$\frac{0+40}{2} \times \frac{100}{27} = 74$
Total	**463**	**74**

Net excess excavated material = $463 - 74 = 389\ \text{yd}^3$

THE CORRECT ANSWER IS: C

37. Existing:

$\Delta H = (2+88.4) - (0+23.0) = 288.4 - 23.0 = 265.4\ \text{ft}$

$\Delta V = 630.32 - 609.39 = 20.93\ \text{ft}$

New:

$\Delta H = (1+15.0) - (0+23.0) = 115.0 - 23.0 = 92\ \text{ft}$

$$\Delta V = \frac{92}{265.4} \times 20.93 = 7.26\ \text{ft}$$

Inv Elev. = $630.32 - 7.26 = 623.06$ ft

The top of the pipe will be above the invert elevation by (60 in. – 6 in.)/12 in./ft = 4.50 ft

$623.06 + 4.50 = 627.56$ ft

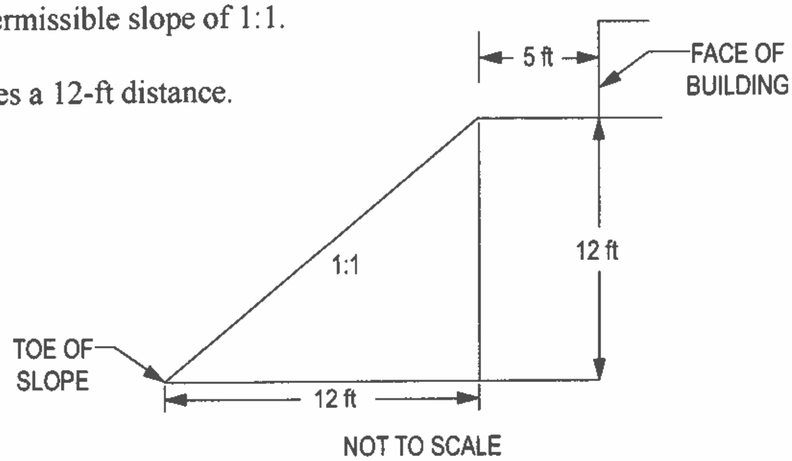
THE CORRECT ANSWER IS: B

38. Rushing erosion is not a stormwater erosion classification.

THE CORRECT ANSWER IS: D

39. Type B soil has a maximum permissible slope of 1:1.

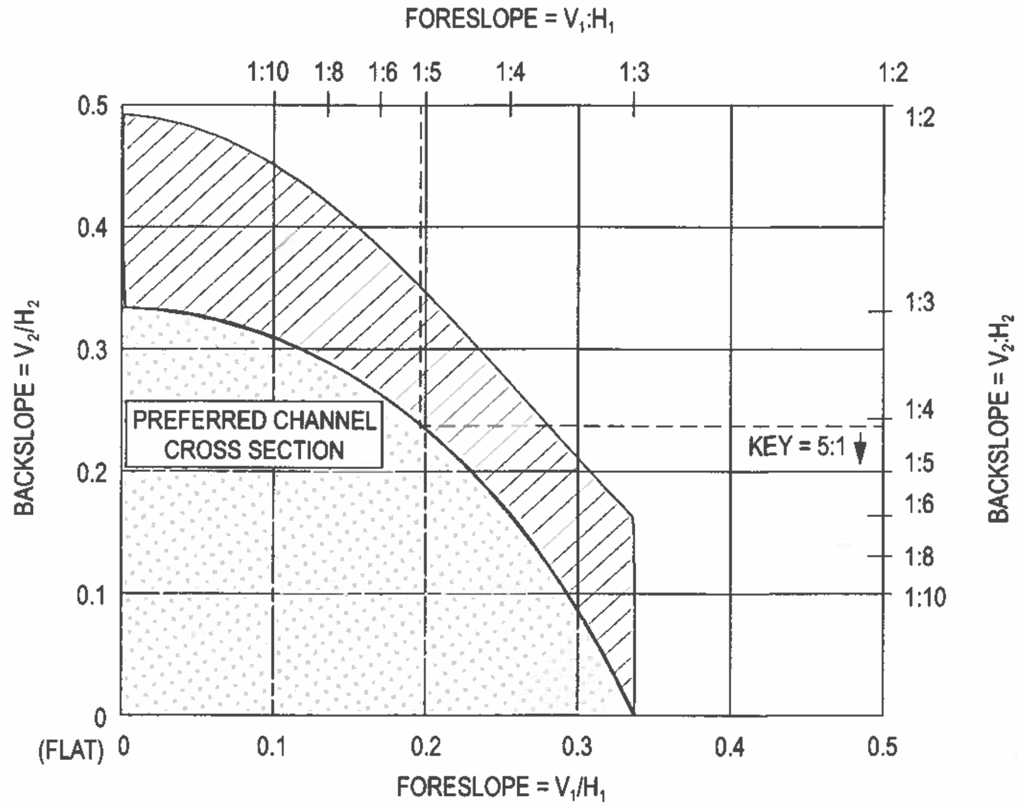
Therefore, a 12-ft depth requires a 12-ft distance.



Because there is a 5-ft perimeter strip, the minimum distance from the toe of the slope to the face of the structure = 12 ft +5 ft = 17 ft.

THE CORRECT ANSWER IS: C

40.



This area is applicable to all Vee ditches, rounded channels with a bottom width less than 2.4 m [8 ft], and trapezoidal channels with bottom widths less than 1.2 m [4 ft].

This area is applicable to rounded channels with bottom width of 2.4 m [8 ft] or more and to trapezoidal channels with bottom widths equal to or greater than 1.2 m [4 ft].

Adapted from AASHTO *Roadside Design Guide*, 4th edition, 2011.

THE CORRECT ANSWER IS: C

41. x mg/L BOD_5 in 15.47 cfs (converted from 10 MGD) + 2 mg/L BOD_5 in 100 cfs = 5 mg/L BOD_5 in 115.47 cfs

Solve for x

x = 24.4 mg/L, which is 75.6% removal.

THE CORRECT ANSWER IS: > 75% and < 76%

42.

$$\text{Flow per clarifier} = \frac{2\ \text{MGD}}{3\ \text{clarifiers}} = 0.667\ \text{MGD}$$

$$\text{Overflow rate} = \frac{667{,}000\ \text{gpd}}{\dfrac{\pi(30)^2}{4}} = \frac{667{,}000}{706.9} = 944\ \text{gpd/ft}^2$$

THE CORRECT ANSWER IS: B

43.

$$\text{Digester volume} = \frac{\pi}{4}D^2H = 0.785\,(60\ \text{ft})^2(8\ \text{ft})$$
$$= 22{,}608\ \text{ft}^3$$

Daily sludge volume = 20,000 gal/day = 0.02 MGD

Sludge solids concentration = 2% = 20,000 mg/L

Daily VSS mass = 8.34 QC

$$= 8.34\ \frac{\text{lb/Mgal}}{\text{mg/L}}(0.02\ \text{MGD})(0.75)(20{,}000\ \text{mg/L})$$
$$= 2{,}502\ \text{lb/day VSS}$$

$$\text{VSS loading} = \frac{\text{daily VSS mass}}{\text{digester volume}} = \frac{2{,}502\ \text{lb/day}}{22{,}608\ \text{ft}^3}$$
$$= 0.111\ \text{lb/(ft}^3\text{-day)}$$

THE CORRECT ANSWER IS: B

44.

$$Q = 2.54\,H^{5/2}$$
$$= (2.54)\left(\frac{13\ \text{in.}}{12\ \text{in./ft}}\right)^{5/2}$$
$$= 3.10\ \text{ft}^3/\text{sec}$$

THE CORRECT ANSWER IS: C

45. $Q = VA$

where:

Q = flow rate

V = velocity

A = area

$Q_{pipe} = Q_{nozzle}$

$V_{pipe} \times A_{pipe} = V_{nozzle} \times A_{nozzle}$

$V_{nozzle} = V_{pipe} \times A_{pipe}/A_{nozzle}$

$$= 5 \text{ fps} \times \frac{\frac{(3.14)(2)^2}{4}}{\frac{(3.14)(0.333)^2}{4}}$$

$$= 5 \text{ fps} \times 36.07 = 180.4 \text{ fps}$$

THE CORRECT ANSWER IS: C

46. $Q = 3$ MGD

Convert the flow rate from MGD to cfs:

$$Q = \left(\frac{3 \times 10^6 \text{ gal}}{\text{day}}\right)\left(\frac{\text{day}}{24 \text{ hr}}\right)\left(\frac{\text{hr}}{60 \text{ min}}\right)\left(\frac{\text{min}}{60 \text{ sec}}\right)\left(\frac{\text{ft}^3}{7.48 \text{ gal}}\right)$$

$$= 4.64 \text{ cfs}$$

$D = 12 \text{ in.} = 1 \text{ ft}$

$$A = \frac{\pi}{4}D^2 = \frac{\pi}{4}(1 \text{ ft})^2 = 0.785 \text{ ft}^2$$

$Q = VA$

$$V = \frac{Q}{A} = \frac{4.64 \text{ cfs}}{0.785 \text{ ft}^2} = 5.91 \text{ ft/sec}$$

$$\text{Velocity head, } h = \frac{V^2}{2g}$$

$$= \frac{(5.91 \text{ ft/sec})^2}{2(32.2 \text{ ft/sec}^2)} = 0.54 \text{ ft}$$

THE CORRECT ANSWER IS: B

47. $Q = C_d A_o \sqrt{2gh}$

where

Q = outflow

C_d = discharge coefficient

A_o = orifice area

g = acceleration of gravity

h = height above centerline of orifice

$$Q = 0.5\left(\frac{\pi\,(3\text{ ft})^2}{4}\right)\sqrt{2(32.2\text{ ft/sec}^2)\left(10\text{ ft} - \frac{3\text{ ft}}{2}\right)}$$

$$= 0.5(7.06)\sqrt{(64.4)(8.5)}$$

$$= 82.6\text{ cfs}$$

THE CORRECT ANSWER IS: B

48. $$\text{bhp} = \frac{\gamma QH}{\left(\frac{550\text{ ft-lb/sec}}{\text{hp}}\right)\eta}$$

where

bhp = pump horsepower

γ = specific weight of water = 62.4 lb/ft^3

Q = pump discharge (ft^3/sec)

H = total dynamic head (ft)

η = pump efficiency

$$Q = 400\text{ gpm}\left(\frac{1\text{ ft}^3/\text{sec}}{448.8\text{ gpm}}\right) = 0.8913\text{ ft}^3/\text{sec}$$

$$H = 75\text{ psi}\left(\frac{2.31\text{ ft}}{\text{psi}}\right) = 173.25\text{ ft}$$

$$20\text{ hp} = \frac{(62.4\text{ lb/ft}^3)(0.8913\text{ ft}^3/\text{sec})(173.25\text{ ft})}{\left(\frac{550\text{ ft-lb/sec}}{\text{hp}}\right)\eta}$$

$$\eta = 0.88 = 88\%$$

THE CORRECT ANSWER IS: D

49. $Q_8 + Q_6 = 2$ cfs $\qquad h_{L_8} = h_{L_6}$

$$h_L = f\frac{L}{D}\left(\frac{V^2}{2g}\right) \qquad Q = AV$$

$$f_8 = 0.024 \qquad L_8 = 3{,}000$$

$$f_6 = 0.020 \qquad L_6 = 4{,}000$$

$$A_8 = \frac{\pi}{4}D_8^2 = \frac{\pi}{4}\left(\frac{8\text{ in.}}{12\text{ in./ft}}\right)^2 = 0.3491\text{ ft}^2$$

$$A_6 = \frac{\pi}{4}D_6^2 = \frac{\pi}{4}\left(\frac{6\text{ in.}}{12\text{ in./ft}}\right)^2 = 0.1963\text{ ft}^2$$

$$\frac{0.024(3{,}000)V_8^2}{(8/12)(2)(32.2)} = \frac{0.020(4{,}000)V_6^2}{(6/12)(2)(32.2)}$$

$$1.677\ V_8^2 = 2.4845\ V_6^2$$

$$V_8^2 = 1.4815\ V_6^2$$

$$V_8 = 1.2172\ V_6$$

$$Q_T = Q_8 + Q_6 = 0.3491(1.2172\ V_6) + 0.1963\ V_6 = 2\text{ cfs}$$

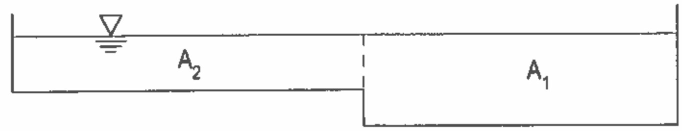
$$V_6 = 3.21\text{ ft/sec}$$

$$Q_6 = 3.21(0.1963) = 0.63\text{ cfs}$$

$$Q_8 = 2 - 0.63 = 1.37\text{ cfs}$$

THE CORRECT ANSWER IS: B

50. For the rectangular compound channel shown in the figure, define A_1 as the area having depth of 4 ft + 6 ft = 10 ft and 50 ft width.



$A_1 = (50 \text{ ft})(10 \text{ ft}) = 500 \text{ ft}^2$

$P_1 = 50 \text{ ft} + 2(4 \text{ ft}) + 6 \text{ ft} = 64 \text{ ft}$

$R_1 = A_1/P_1 = 500 \text{ ft}^2/64 \text{ ft} = 7.81 \text{ ft}$

$K_1 = (1.49/n_1)(A_1)(R_1)^{2/3} = (1.49/0.05)(500)(7.81)^{2/3} = 58{,}652 \text{ cfs}$

Define A_2 as the area having unknown width W and flow depth of 6 ft:

$A_2 = 6W$ $\quad$ $P_2 = W + 6 \text{ ft}$ $\quad$ $R_2 = (6W)/(W + 6 \text{ ft})$

$K_2 = (1.49/n_2)(A_2)(R_2)^{2/3} = (1.49/0.14)(6W)[(6W)/(W+6)]^{2/3}$

$Q = (K_1 + K_2)S^{1/2} = 3{,}000 = [58{,}652 + [(1.49/0.14)(6W)[(6W)/(W+6)]^{2/3}]](0.001)^{1/2}$

or $[(6W)^{5/3}]/(W+6)^{2/3} = 3{,}402.9$

Solving for W by trial yields W = 176 ft

THE CORRECT ANSWER IS: A

51. Convert the design flow from MGD to cfs:

(3.0 MGD)(1.5472 cfs/MGD) = 4.64 cfs

Solve the Manning equation for diameter of circular pipe D assuming full pipe and fully turbulent flow:

$$D = \left(\frac{2.159Qn}{S^{1/2}}\right)^{3/8} = \left(\frac{(2.159)(4.64)(0.012)}{0.002^{1/2}}\right)^{3/8} = 1.45 \text{ ft} = 17.4 \text{ in.}$$

The minimum diameter of a replacement line that can handle the design flow is 18 in.

THE CORRECT ANSWER IS: C

52. Given: $Q_1 = 1{,}815 \text{ cfs},\ H_1 = 6 \text{ ft},\ L_1 = 40 \text{ ft}$
Require: L_2 for $Q_2 = 2{,}500$ cfs and $H_2 = 6$ ft

$$Q = CLH^{3/2}$$
$$Q_1 = C_1 L_1 {H_1}^{3/2}$$
$$1{,}815 \text{ cfs} = C_1\,(40 \text{ ft})(6 \text{ ft})^{3/2}$$
$$C_1 = 3.087$$
$$C_1 = C_2 = 3.087$$
$$Q_2 = C_2 L_2 {H_2}^{3/2}$$
$$2{,}500 \text{ cfs} = 3.087\, L_2\,(6 \text{ ft})^{3/2}$$
$$L_2 = 55.1 \text{ ft}$$
$$\Delta L = L_2 - L_1 = 55.1 \text{ ft} - 40 \text{ ft} = 15.1 \text{ ft}$$

Alternate solution:

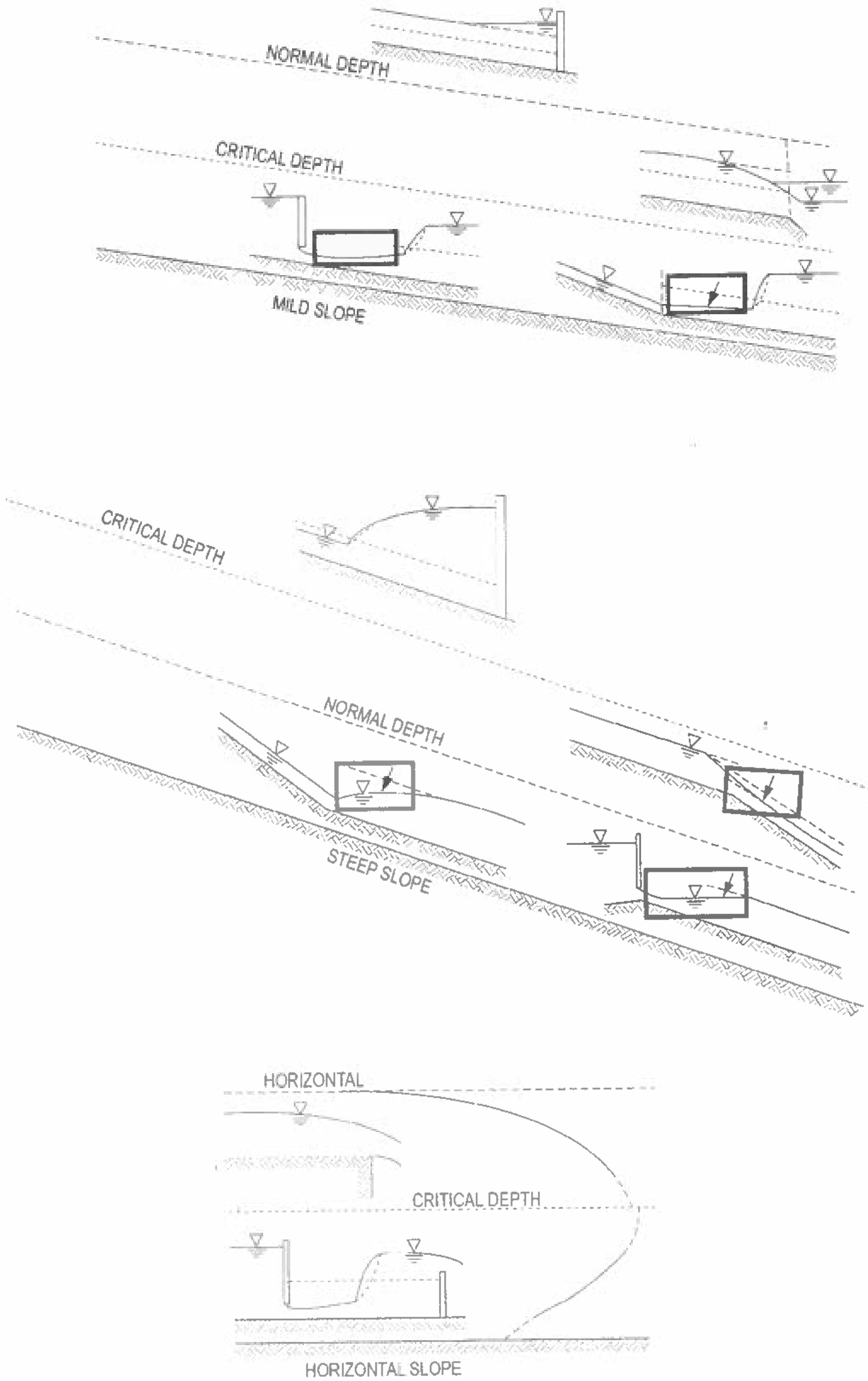
$$\frac{Q_1}{Q_2} = \frac{L_1}{L_2}$$
$$\frac{1{,}815 \text{ cfs}}{2{,}500 \text{ cfs}} = \frac{40 \text{ ft}}{L_2}$$
$$L_2 = 55.1 \text{ ft}$$
$$\Delta L = L_2 - L_1 = 55.1 \text{ ft} - 40 \text{ ft} = 15.1 \text{ ft}$$

THE CORRECT ANSWER IS: A

53.
$$Q = V_1 A_1 = (50 \text{ ft/sec})(3.8 \text{ ft})(35 \text{ ft}) = 6{,}650 \text{ ft}^3/\text{sec}$$
$$F_1 = \frac{V_1}{\sqrt{gD_1}} = \frac{50 \text{ ft/sec}}{\sqrt{(32.2 \text{ ft/sec}^2)(3.8 \text{ ft})}} = 4.52$$
$$\frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1 + 8{F_1}^2} - 1\right) = \frac{1}{2}\left(\sqrt{1 + 8(4.52)^2} - 1\right) = 5.91$$
$$y_2 = 5.91\, y_1 = 5.91(3.8 \text{ ft}) = 22.46 \text{ ft}$$
$$V_2 = \frac{Q_2}{A_2} = \frac{6{,}650 \text{ ft}^3/\text{sec}}{(35 \text{ ft})(22.46 \text{ ft})} = 8.46 \text{ ft/sec}$$
$$F_2 = \frac{V_2}{\sqrt{gD_2}} = \frac{8.46 \text{ ft/sec}}{\sqrt{(32.2 \text{ ft/sec}^2)(22.46 \text{ ft})}} = 0.31$$

THE CORRECT ANSWER IS: C

54.



THE CORRECT PROFILES ARE SHOWN IN THE FIGURE ABOVE.

55. The time of concentration that should be used for design is the longest time for overland flow (Area 3) plus time in Pipe AB.

Time in pipe is equal to the length divided by the velocity in the pipe which is:

$$t = \frac{L}{V} = \frac{450\text{ ft}}{3\text{ ft/sec}} = 150\text{ sec} = 2.5\text{ min}$$

Time of concentration to Point B = 30 min + 2.5 min = 32.5 min

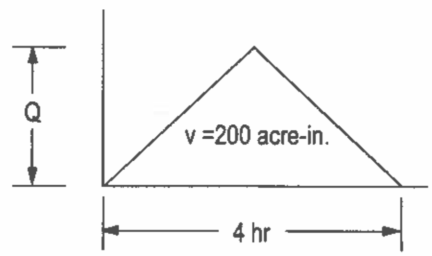
THE CORRECT ANSWER IS: C

56. Find Q:

Area of triangle = bh/2 = 200 acre-in.

= 4Q/2 = 200 acre-in.

$$Q = \frac{200(2)}{4} = 100\text{ cfs/in. of precipitation}$$



THE CORRECT ANSWER IS: B

57. Designate the upper portion of the basin as Area 1 and the lower portion as Area 2.

From Figure 1, L_1 = 400 ft, L_2 = 1,700 ft

From Figure 3, V_1 = 2.2 ft/sec, V_2 = 3.4 ft/sec

$$T_c = \left(\frac{L_1}{V_1} + \frac{L_2}{V_2}\right)/60$$

$$= \left(\frac{400}{2.2} + \frac{1,700}{3.4}\right)/60$$

$$= 11.4\text{ min}$$

From Figure 2, for T_c = 11.4 min and 50-year storm frequency, rainfall intensity = 6.5 in./hr

THE CORRECT ANSWER IS: C

58. T_c to Point 4 (Lake) = Overland flow and pipe flow times

Pipe flow times:

$$\text{Pipe } 1 \rightarrow 2 = \frac{400 \text{ ft}}{3.2 \text{ ft/sec}} \times \frac{\text{min}}{60 \text{ sec}} = 2.08 \text{ min}$$

$$\text{Pipe } 2 \rightarrow 3 = \frac{400 \text{ ft}}{3.6 \text{ ft/sec}} \times \frac{\text{min}}{60 \text{ sec}} = 1.85 \text{ min}$$

$$\text{Pipe } 3 \rightarrow 4 = \frac{400 \text{ ft}}{3.9 \text{ ft/sec}} \times \frac{\text{min}}{60 \text{ sec}} = 1.71 \text{ min}$$

Times of concentration:

$$\begin{aligned} \text{From A} \rightarrow \text{Lake} &= 10 + 2.08 + 1.85 + 1.71 = 15.64 \text{ min} \\ \text{B} \rightarrow \text{Lake} &= 12 + 1.85 + 1.71 = 15.56 \text{ min} \\ \text{C} \rightarrow \text{Lake} &= 12 + 1.71 = 13.71 \text{ min} \\ \text{D} \rightarrow \text{Lake} &= 7 = 7 \text{ min} \end{aligned}$$

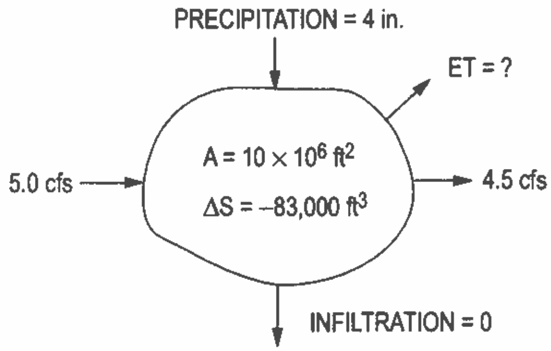
The longest time of concentration should be used (15.64 min)

THE CORRECT ANSWER IS: B

59. Peak discharge occurs when storm duration is greater than or equal to the time of concentration.

THE CORRECT ANSWER IS: A

60.



$$\begin{aligned}\Delta S &= \text{in} - \text{out} \\ &= \text{inflow} + \text{precipitation} - \text{outflow} - \text{ET} - \text{infiltration}\,(=0)\end{aligned}$$

$$\begin{aligned}\text{ET} &= (\text{inflow} - \text{outflow}) + \text{precipitation} - \Delta S \\ &= (5.0\text{ cfs} - 4.5\text{ cfs})(86{,}400\text{ sec/day})(30\text{ days}) + (4\text{ in.})(1\text{ ft}/12\text{ in.})(10 \times 10^6\text{ ft}^2) - (-83{,}000\text{ ft}^3) \\ &= 1{,}296{,}000 + 3{,}333{,}333 - (-83{,}000) \\ &= 4{,}712{,}333\text{ ft}^3\end{aligned}$$

$$\text{Depth} = \frac{\text{volume}}{\text{area}} = \frac{4{,}712{,}333\text{ ft}^3}{10 \times 10^6\text{ ft}^2} \times 12\text{ in./ft} = 5.65\text{ in.}$$

THE CORRECT ANSWER IS: C

61. The area under the curve represents the rainfall (in.) that has fallen over the site.

Area = (10)(0.02 + 0.03 + 0.02 +0.05 + 0.08 + 0.04 + 0.03 + 0.06 + 0.03 + 0.01) = 3.7 in.

The total volume resulting from the rainfall event over the 100-acre site is:

$$(3.7\text{ in.})(100\text{ acres})\left(\frac{43{,}560\text{ ft}^2}{1\text{ acre}}\right)\left(\frac{1\text{ ft}}{12\text{ in.}}\right)=1{,}343{,}100\text{ ft}^3$$

$$\text{Infiltration}=\left(\frac{0.2\text{ in.}}{10\text{ min}}\right)(30\text{ min})(100\text{ acres})\left(\frac{43{,}560\text{ ft}^2}{1\text{ acre}}\right)\left(\frac{1\text{ ft}}{12\text{ in.}}\right)=217{,}800\text{ ft}^3$$

$$\text{Required pond volume}=1{,}343{,}100\text{ ft}^3-217{,}800\text{ ft}^3-440{,}000\text{ ft}^3=685{,}300\text{ ft}^3$$

$$\text{Pond depth}=\frac{685{,}300\text{ ft}^3}{43{,}560\text{ ft}^2}=15.7\text{ ft}$$

THE CORRECT ANSWER IS: A

62. Aquifer transmissivity, T, is the sum of the transmissivities of the three layers of the aquifer. Transmissivity is the product of the hydraulic conductivity and the thickness.

$$\begin{aligned}T &= K_1b_1+K_2b_2+K_3b_3\\ &=(30)(30)+(3)(60)+(0.3)(210)\\ &=1{,}143\text{ ft}^2/\text{day}\end{aligned}$$

THE CORRECT ANSWER IS: C

63. Area is for a 1-ft width of aquifer

$$\begin{aligned}Q &= KA\frac{dh}{dr}\\ &=\left((0.8\text{ ft/min})(30\text{ ft})(1\text{ ft})\left(\frac{5}{1{,}000}\right)\right)\times\frac{1\text{ min}}{60\text{ sec}}\\ &=0.002\text{ cfs per foot width of aquifer}\end{aligned}$$

THE CORRECT ANSWER IS: C

64. $Q = (1{,}900 \text{ gpm})(60 \text{ min/hr})(24 \text{ hr/day})\left(1 \text{ ft}^3/7.48 \text{ gal}\right) = 365{,}775 \text{ ft}^3/\text{day}$

$$Q = \frac{\pi K(h_2^2 - h_1^2)}{\ln(r_2/r_1)}$$

$$K = \frac{\ln\left(\frac{r_2}{r_1}\right)Q}{\pi(h_2^2 - h_1^2)} = \frac{\ln\left[\frac{1{,}050 \text{ ft}}{(8 \text{ in.})\left(\frac{\text{ft}}{12 \text{ in.}}\right)}\right]\left(365{,}775 \text{ ft}^3/\text{day}\right)}{\pi[(140-27)^2 - (140-49)^2]} = 191 \text{ ft/day}$$

THE CORRECT ANSWER IS: C

65. Total daily flow rate = domestic + commercial = 70 + 10 = 80 gal/(capita-day)
Population at the end of 5 years = 25,000(115%) = 28,750
Daily flow rate in 5 years = 28,750(80) = 2,300,000 gal/day = 2.3 MGD
Peak flow rate = 2.3(2.5) = 5.75 MGD

THE CORRECT ANSWER IS: D

66. $$V_{PS} = \frac{(\text{lb solids})(\text{solids capture})}{(\text{underflow})\,\gamma_{H_2O}}$$

$$= \frac{(1{,}000 \text{ lb/day})(0.9)}{(0.09)\left(62.4\frac{\text{lb}}{\text{ft}^3}\right)} = 160.3 \text{ ft}^3/\text{day}$$

THE CORRECT ANSWER IS: C

67. $F/M = (QS_o)/(VX)$

where

F/M = food-to-microorganism ratio

Q = flow rate

$S_o = BOD_5$ inflow to the aeration tank

V = volume of aeration tank

X = MLVSS in aeration tank

$V = (QS_o)/[(F/M)(X)]$

$S_o = (\text{influent } BOD_5)(1 - 0.35)$

$= (200 \text{ mg/L})(0.65) = 130 \text{ mg/L}$

$$V = \left\{(10 \text{ MGD})(130 \text{ mg/L})/[(0.2 \text{ day}^{-1})(2,200 \text{ mg/L})(7.48 \text{ gal/ft}^3)]\right\} \times \frac{10^6 \text{ gal}}{1 \text{ MG}}$$

$= 394,993 \text{ ft}^3$

THE CORRECT ANSWER IS: C

68. About 2 moles O_2 are required per mole NH_4^+

THE CORRECT ANSWER IS: B

69.

$$V = \frac{M}{S_{sl}\,\rho_w P_s}$$

where

V = daily sludge volume

M = daily mass of solids

S_{sl} = specific gravity of sludge

ρ_w = specific weight of water

P_s = percent solids expressed as a decimal

$$\text{Sludge volume} = \frac{6{,}500 \text{ lb solids/day}}{1.05(62.4 \text{ lb/ft}^3)(0.05 \text{ lb solids/lb sludge})}$$

$$= 1{,}984 \text{ ft}^3\text{/day}$$

$$\text{Digester volume} = (\text{daily sludge volume})(\text{retention time}) = (1{,}984 \text{ ft}^3\text{/day})(14 \text{ days})$$

$$= 27{,}778 \text{ ft}^3$$

THE CORRECT ANSWER IS: D

70.

$$\frac{2 \text{ cylinders} \times \dfrac{150 \text{ lb}}{\text{cylinder}}}{\left(8.34 \times 0.5 \text{ MGD} \times 8 \dfrac{\text{mg}}{\text{L}}\right)\dfrac{\text{lb}}{\text{day}}} = \frac{300}{33.36} = 8.99 \text{ days}$$

THE CORRECT ANSWER IS: B

71. Flow after mixing = 50 + 20 = 70 cfs

Mass balance on phosphorus, P:

$$(50)(0.02) + (20)(0.5) = 70\,P$$

$$P = \frac{(50)(0.02) + (20)(0.5)}{70}$$

$$= 0.16 \text{ mg/L, which is greater than } 0.015 \text{ mg/L}$$

Therefore, algae will grow and consume the P. As the phosphorus drops below 0.015 mg/L, algae will begin to die off. Therefore, the algae concentration will increase first and then decrease.

THE CORRECT ANSWER IS: D

72. Mass of oxygen to be added to River A to increase DO from 5.5 mg/L to 6.2 mg/L

$$= (6.2 - 5.5)\left(\frac{115 \text{ ft}^3}{\text{sec}}\right)\left(\frac{7.48 \text{ gal}}{\text{ft}^3}\right)\left(\frac{86,400 \text{ sec}}{\text{day}}\right)\left(\frac{1}{10^6}\right)8.34$$

$= 433.9$ lb/day.

Aeration rate = 0.28 lb/(day-ft)

∴Linear feet of aerator = 433.9/0.28

= 1,549.6 ft

THE CORRECT ANSWER IS: C

73.

$$\text{CDI} = \frac{(\text{Conc})(\text{Intake})(\text{Exposure})}{(\text{Body weight})(\text{Lifetime})} = \frac{\left(0.5\frac{\text{mg}}{\text{L}}\right)\left(2.3\frac{\text{L}}{\text{day}}\right)(6 \text{ yr})(365 \text{ days/yr})}{(78 \text{ kg})(75 \text{ yr})(365 \text{ days/yr})}$$

$$= 1.2 \times 10^{-3} \frac{\text{mg}}{\text{kg}\bullet\text{day}}$$

$$\text{Risk} = \left(1.2 \times 10^{-3} \frac{\text{mg}}{\text{kg}\bullet\text{day}}\right)\left(4.5 \frac{\text{kg}\bullet\text{day}}{\text{mg}}\right) = 0.005 = 5 \times 10^{-3}$$

THE CORRECT ANSWER IS: C

74. Points B and E are the two high points in the line with the exception of the tank, which vents to the atmosphere and does not need an air release valve.

THE CORRECT ANSWERS ARE: B and E

75. By the constant percentage or geometric method:

$$\ln p_2 = \ln p_1 + k_p(t_2 - t_1)$$

where

p_2 = population at future time t_2
p_1 = population at time t_1
k_p = geometric growth rate constant

Find k_p:

$$k_p = (\ln p_2 - \ln p_1)/(t_2 - t_1)$$

$$= (\ln 92{,}000 - \ln 85{,}000)/10 = (11.429 - 11.350)/10 = 0.0079137$$

$$\ln p = \ln 92{,}000 + (0.0079137)(2{,}017 - 2{,}010) = 11.48494$$

$$p = 97{,}240$$

Additional demand = $(97{,}240 - 92{,}000)(160 \text{ gpcd}) = 838{,}400$ gal/day

THE CORRECT ANSWER IS: A

76. Floodplain elevation and surface overflow rate are not considerations for elevated potable water tanks.

Tank Design Parameters

Maximum elevation
Flight path
Pump total discharge head (TDH)

Minimum elevation
Service pressure

Volume
Fire-flow duration
Chlorine residual

THE CORRECT ANSWERS ARE SHOWN ABOVE.

77. Use equation for velocity gradient G-value:

$G = (P/\mu V)^{1/2}$

where:

G = velocity gradient, fps/ft or sec^{-1}
P = power input, ft-lb/sec
μ = dynamic viscosity, lb-sec/ft^2
V = volume, ft^3

$\mu = 2.735 \times 10^{-5}$ lb-sec/ft^2

Flow rate = (1,000,000 gal/day)(ft^3/7.48 gal)(day/1,440 min) = 92.84 ft^3/min

Since the design retention time is 1 min, the volume of the rapid mix unit is 92.84 ft^3

$G^2 = P/\mu V$

$$P = G^2 \mu V$$
$$= (700\ sec^{-1})^2 (2.735 \times 10^{-5}\ \text{lb-sec/ft}^2)(92.84\ \text{ft}^3)$$
$$= 1{,}244\ \text{ft-lb/sec}$$

THE CORRECT ANSWER IS: B

78. Area of filter = (16)(40) = 640 ft^2

Since the required air wash rate is 5 scfm/ft^2, the airflow rate = (640)(5) = 3,200 scfm

THE CORRECT ANSWER IS: C

79. The lime needed to remove carbonate hardness is

lime								
lime	=	CO_2	+	bicarbonate	+	magnesium to be removed	+	excess
	=	50	+	120	+	0	+	20
	=	190 mg/L as $CaCO_3$						

THE CORRECT ANSWER IS: C

80. $P_B = \$10{,}000{,}000 + \$200{,}000\,(P/A, 6\%, 20)$ (11.47)

$= \$12.29$ million

$P_L = \$1{,}000{,}000 + \$600{,}000\,(P/A, 3\%, 40)$ (23.12) This is for semiannual payments for 20 years.

$= \$14.87$ million

$P_B - P_L = 12.29 - 14.87 = -\$2.58$ million

P_B is better by almost \$2.6 million.

THE CORRECT ANSWER IS: A