Instructor’s Manual
to accompany

BASIC ENVIRONMENTAL TECHNOLOGY
Water Supply, Waste Management, and Pollution Control
Fifth Edition

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This manual provides instructors with (a) text page references and Internet URLs where answers to the end-of-chapter Review Questions can be found, (b) worked out solutions to each of the Practice Problems, and (c) supplemental problems and 100 multiple choice questions (and answers) that can be incorporated in tests or a final examination.

Generally, answers to end-of-chapter Practice Problems are rounded-off to reflect the precision of the data and/or the accuracy of the assumed factors in the problems. These answers are also listed in Appendix F of the text for students to use in checking their work. (The author has made every attempt to keep errors to a minimum. He can be notified of any mistakes that may be found in the text or in this manual at: nathanson1@comcast.net).

CHAPTER 1  BASIC CONCEPTS

Review Question Page References

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(4) 7   (18) 18  (32) http://www.usgs.gov/nawqa/
(5) 7   (19) 17-19 (33) http://www.envirosources.com
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(There are no Practice Problems for Chapter 1)
CHAPTER 2   HYDRAULICS

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(21) 51 (22) www.iihs.uiowa.edu/projects/index.html
(23) www.usbr.gov/wrrl (24) www.envirosources.com

Solutions to Practice Problems

1. \[ P = 0.43 \times h \] (Equation 2-2b)
   \[ P = 0.43 \times 50 \text{ ft} = 22 \text{ psi} \] at the bottom of the reservoir
   \[ P = 0.43 \times (50 - 30) = 0.43 \times 20 \text{ ft} = 8.6 \text{ psi} \] above the bottom

2. \[ h = 0.1 \times P = 0.1 \times 50 = 5 \text{ m} \] (Equation 2-3a)

3. Depth of water above the valve: \[ h = (78 \text{ m} - 50 \text{ m}) + 2 \text{ m} = 30 \text{ m} \]
   \[ P = 9.8 \times h = 9.8 \times 30 = 294 \text{ kPa} \approx 290 \text{ kPa} \] (Equation 2-2a)

4. \[ h = 2.3 \times P = 2.3 \times 50 = 115 \text{ ft} \] in the water main
   \[ h = 115 - 40 = 75 \text{ ft} \]
   \[ P = 0.43 \times 75 = 32 \text{ psi} \] 40 ft above the main (Equation 2-2b)

5. Gage pressure \( P = 30 + 9.8 \times 1 = 39.8 \text{ kPa} \approx 40 \text{ kPa} \)
   Pressure head (in tube) = \( 0.1 \times 40 \text{ kPa} = 4 \text{ m} \)

6. \[ Q = A \times V \] (Eq. 2-4), therefore \( V = Q/A \)
   \[ A = \pi D^2/4 = \pi (0.3)^2/4 = 0.0707 \text{ m}^2 \]
   \[ 100 \text{ L/s} \times 1 \text{ m}^3/1000L = 0.1 \text{ m}^3/s \]
   \[ V = 0.1 \text{ m}^3/s / 0.707 \text{ m}^2 = 1.4 \text{ m/s} \]

7. \[ Q = (500 \text{ gal/min}) \times (1 \text{ min/60 sec}) \times (1 \text{ ft}^3/7.5 \text{ gal}) = 1.11 \text{ cfs} \]
   \[ A = Q/V \] (from Eq. 2-4)
   \[ A = 1.11 \text{ ft}^3/\text{sec} / 1.4 \text{ ft/sec} = 0.794 \text{ ft}^2 \]
   \[ A = \pi D^2/4, \] therefore \( D = \sqrt{4A}/\pi = \sqrt{(4)(0.794)}/\pi = 1 \text{ ft} = 12 \text{ in.} \)
8. \( Q = A_1 \times V_1 = A_2 \times V_2 \) (Eq. 2-5)

Since \( A = \pi D^2/4 \), we can write
\[
D_1^2 \times V_1 = D_2^2 \times V_2 \quad \text{and} \quad V_2 = V_1 \times (D_1^2/D_2^2)
\]
In the constriction, \( V_2 = (2 \text{ m/s}) \times (4) = 8 \text{ m/s} \)

9. Area of pipe A = \( \pi (0.3)^2/4 = 0.0707 \text{ m}^2 \)
   Area of pipe B = \( \pi (0.1)^2/4 = 0.00785 \text{ m}^2 \)
   Area of pipe C = \( \pi (0.2)^2/4 = 0.03142 \text{ m}^2 \)
   \( Q_A = Q_B + Q_C = 0.00785 \text{ m}^2 \times 2 \text{ m/s} + 0.03142 \text{ m}^2 \times 1 \text{ m/s} \)
   \[= 0.04712 \text{ m}^3/\text{s} \text{ (from continuity of flow: } Q_{\text{IN}} = Q_{\text{OUT}})\]
   \( V_A = Q_A/A_A = 0.4712/0.0707 \approx 0.67 \text{ m/s (from Eq. 2-4)} \)

10. \( p_1/w + V_1^2/2g = p_2/W + V_2^2/2g \) (Eq. 2-8)

\( A_1 = \pi (1.33)^2/4 = 1.4 \text{ ft}^2 \) \quad \( A_2 = \pi (0.67)^2/4 = 0.349 \text{ ft}^2 \)
\[
V_1 = 6/1.4 = 4.29 \text{ ft/sec} \quad V_2 = 6/0.349 = 17.2 \text{ ft/sec}
\]
\( w = 62.4 \text{ lb/ft}^3 \text{ and } g = 32.2 \text{ ft/sec}^2 \)
From Eq. 2-8, and multiplying \( \text{psi} \times 144 \text{ in}^2/\text{ft}^2 \) to get \( \text{lb/ft}^2 \)
\[
50(144)/62.4 + 4.29^2/2(32.2) = p_2(144)/62.4 + 17.2^2/2(32.2)
\]
115.38 + 0.28578 = 2.3076\( p_2 + 4.5937 \)
\( p_2 = 111.07/2.307 \approx 48 \text{ psi} \)

11. \( p_1/w + v_1^2/2g = p_2/w + v_2^2/2g \) (Eq. 2-8)

\( A_1 = \pi (0.300)^2/4 = 0.0707 \text{ m}^2 \) \quad \( A_2 = \pi (0.100)^2/4 = 0.00785 \text{ m}^2 \)
\[
Q = 50 \text{ L/s} \times 1 \text{ m}^3/1000 \text{ L} = 0.05 \text{ m}^3/\text{s}
\]
\( V_1 = 0.05/0.0707 = 0.70721 \text{ m/sec} \quad V_2 = 0.05/0.00785 = 6.369 \text{ m/sec} \)
\( w = 9.81 \text{ kN/m}^3 \text{ and } g = 9.81 \text{ m/s}^2 \); From Eq. 2-8,
\[
700/2(9.81) + 0.70721^2/2(9.81) = p_2/2(9.81) + 6.369^2/2(9.81)
\]
35.67789 + 0.02549 = 0.05097\( p_2 + 2.06775 \text{ and } p_2 = 660 \text{ kPa} \)
12. From Figure 2.15, with $Q = 200 \text{ L/s}$ and $D = 600 \text{ mm}$, read $S = 0.0013$.
   Therefore $h = S \times L = 0.0013 \times 1000 \text{ m} = 1.3 \text{ m}$
   Pressure drop $p = 9.8 \times 1.3 = 12.7 \approx 13 \text{ kPa per km}$

13. $h = 2.3 \times 20 = 46 \text{ ft}$ and $S = 46/5280 = 0.0087$ (where $1 \text{ mi} = 5280 \text{ ft}$)
   From Figure 2.15, with $Q = 1000 \text{ gpm}$ and $S = 0.0087$, read $D = 10.3 \text{ in}$.
   Use a 12 in. standard diameter pipe

14. $S = 10/1000 = 0.01$
   From the nomograph (Figure 2.15) read $Q \approx 100 \text{ L/s} = 0.1 \text{ m}^3/\text{s}$
   Check with Eq. 2-9: $Q = 0.28 \times 100 \times 0.3^{2.63} \times 0.01^{0.54} \approx 0.1 \text{ m}^3/\text{s}$ OK

15. Use (Eq. 2-10): $Q = C \times A^2 \times \{(2g(p_1 - p_2)/w)/(1 - (A_2/A_1)^2)^{1/2}$
   where $A_1 = \pi(6)^2/4 = 28.27 \text{ in}^2$ and $A_2 = \pi(3)^2/4 = 7.07 \text{ in}^2$
   $g = 32.2 \text{ ft/s}^2 = 386.4 \text{ in/s}^2$
   $w = 62.4 \text{ lb/ft}^3 \times 1 \text{ ft}^3/12^3 \text{ in}^3 = 0.0361 \text{ lb/in}^3$
   $Q = 0.98 \times 7.07 \times \{(2(386.4)(10)/0.0361)/(1 - (7.07/28.27)^2)^{1/2}$
   $Q = 0.98 \times 7.07 \times \sqrt{228,354} = 3311 \text{ in}^3/\text{s} = 1.9 \text{ cfs} \approx 2 \text{ cfs}$

16. Use (Eq. 2-10): $Q = C \times A^2 \times \{(2g(p_1 - p_2)/w)/(1 - (A_2/A_1)^2)^{1/2}$
   $A_1 = \pi(0.15)^2/4 = 0.01767 \text{ m}^2$ and $A_2 = \pi(0.075)^2/4 = 0.00442 \text{ m}^2$
   $g = 9.81 \text{ m/s}^2$  $w = 9.81 \text{ kN/m}^3$
   $1 - (A_2/A_1)^2 = 1 - (0.00442/0.01767)^2 = 0.93743$
   $Q = 0.98 \times 0.00442 \times \{(2(9.81)(100)/9.81)/0.93743)^{1/2} = 0.063 \text{ m}^3/\text{s}$
   (or, $Q = 0.063 \text{ m/s} \times 1000 \text{ Lm}^3 = 63 \text{ L/s}$)

17. Use Manning's nomograph (Figure 2.21): With $D = 800 \text{ mm} = 80 \text{ cm}$, and
   $S = 0.2\% = 0.002$, read $Q = 0.56 \text{ m}^3/\text{s} = 560 \text{ L/s}$ and $V = 1.17 \text{ m/s}$

18. $S = 1.5/1000 = 0.015$; from Fig. 2.21, $Q \approx 1800 \text{ gpm}$ and $V \approx 2.3 \text{ ft/s}$

19. $Q = 200 \text{ L/s} = 0.2 \text{ m}^3/\text{s}$; from Fig. 2.21, $D \approx 42 \text{ cm}$; use 450 mm pipe
20. \( Q = 7 \text{ mgd} = 7,000,000 \text{ gal/day} \times 1 \text{ day}/1440 \text{ min} = 4900 \text{ gpm} \)

From Fig. 2.21, with 36 in and 4900 gpm: \( S = 0.00027, \ V = 1.54 \text{ ft/s} \)

Since 1.54 ft/s is less than the minimum self-cleansing velocity of 2 ft/s, it is necessary to increase the slope of the 36 in pipe.

From Fig. 2.21, with 36 in and 2 ft/s: \( S = 0.00047 = 0.047\% \approx 0.05\% \)

21. For full-flow conditions, with \( D = 300 \text{ mm} \) and \( S = 0.02 \), read from Fig. 2.21: \( Q = 0.135 \text{ m}^3/\text{s} = 135 \text{ L/s} \) and \( V = 2 \text{ m/s} \)

\[ q/Q = 50/135 = 0.37 \]

From Fig. 2.22, \( d/D = 0.42 \) and \( v/V = 0.92 \)

Depth at partial flow \( d = 0.42 \times 300 = 126 \text{ mm} \approx 130 \text{ mm} \)

Velocity at partial flow \( v = 0.92 \times 2 \approx 1.8 \text{ m/s} \)

22. For full-flow conditions, from Fig. 2.21 read \( Q = 1800 \text{ gpm} \).

From Fig. 2.22, the maximum value of \( q/Q = 1.08 \) when \( d/D = 0.93 \). Therefore, the highest discharge capacity for the 18 in pipe, \( q_{\text{max}} = 1800 \times 1.08 \approx 1900 \text{ gpm} \), would occur at a depth of \( d = 18 \times 0.93 \approx 17 \text{ in} \).

23. For full-flow conditions, from Fig. 2.21 read \( Q = 0.55 \text{ m}^3/\text{s} = 550 \text{ L/s} \).

From Fig. 2.22, the maximum value of \( v/V = 1.15 \) when \( d/D = 0.82 \). Therefore, the highest flow velocity for the 900 mm pipe, \( v_{\text{max}} = 0.9 \times 1.15 \approx 1 \text{ m/s} \), would occur at a depth of \( d = 900 \times 0.82 \approx 740 \text{ mm} \)

When the flow occurs at that depth, \( q/Q = 1.05 \) and the discharge \( q = 580 \text{ L/s} \)

24. \( S = 0.5/100 = 0.005 \)

For full-flow conditions, \( Q = 0.44 \text{ m}^3/\text{s} = 440 \text{ L/s} \) and \( V = 1.6 \text{ m/s} \)

Since \( d/D = 200/600 = 0.33 \), from Fig. 2.22 \( q/Q = 0.23 \) and \( v/V = 0.8 \)

Therefore, \( q = 440 \times 0.23 \approx 100 \text{ L/s} \) and \( v = 1.6 \times 0.8 \approx 1.3 \text{ m/s} \)

25. \( Q = A \times V = 2 \times 0.75 \times 25/75 = 0.5 \text{ m}^3/\text{s} = 500 \text{ L/s} \)

26. From Eq. 2-12, \( Q = 2.5 \times (4/12)^{2.5} = 0.16 \text{ cfs} \)

27. \( 150 \text{ mm} \times 1 \text{ in} / 25.4 \text{ mm} \times 1 \text{ ft/12 in} = 0.492 \text{ ft} \)

From Eq. 2-12, \( Q = 2.5 \times (0.492)^{2.5} = 0.425 \text{ cfs} \times 28.32 \text{ L/ft}^3 \approx 12 \text{ L/s} \)

28. From Eq. 2-13, \( Q = 3.4 \times (20/12) \times (10/12)^{1.5} = 4.3 \text{ cfs} \approx 120 \text{ L/s} \)