Solutions Manual

for

Introduction to Environmental Engineering

Third Edition

Susan M. Morgan, P.E.
Southern Illinois University Edwardsville

P. Aarne Vesilind, P.E.
Retired, Bucknell University

Lauren G. Heine
Clean Production Action

Table of Contents

Acknowledgments

This manual was originally composed by Ms. Lauren Bartlett. Special thanks to Dr. Steven Hanna and Mr. Robert Whitworth for assistance on the second edition. Thanks to those who provided corrections and suggestions to incorporate in the third edition, in particular Dr. R. L. Droste, P.Eng., of the University of Ottawa.

Supplemental Spreadsheets

Spreadsheets to calculate BOD, the DO sag curve, lime-soda softening chemicals, and dispersion have been developed and are available online for instructors to create their own problems.

Corrections and Suggestions

Send suggestions for modifications and corrections to the text, solutions, and spreadsheets to Dr. Susan Morgan at:

smorgan@siue.edu

or

618-650-2555 (fax)

or

Department of Civil Engineering
Southern Illinois University Edwardsville
Edwardsville, IL 62026-1800

Chapter 1

Section 1.2.1

1. Most people assume it is safe, as they assume most products they buy are safe. Is it the government's responsibility? The product manufacturer's? The seller's?

2. There are several types of hepatitis and many routes to exposure. Hepatitis A is the most prevalent. Hepatitis A and hepatitis E are mainly transmitted through the fecal-oral route, while hepatitis B, C, and D are spread through blood or other body fluids (e.g., saliva, semen, and urine). Hepatitis can be transmitted sexually as well as through shared utensils (e.g., razors and toothbrushes) and un-sterile instruments and needles (including intravenous drug use).

3. Is the university at fault? The family of the children? The city? The water company?

Section 1.2.2

1. Lowest risk that is practical—i.e., technically, socially, and economically feasible. Issues – wearing seat belts, distractions while driving (e.g., cell phones, radio, talking), heavier, safer cars vs. lighter, fuel efficient cars, etc.

2. Why is this the most important issue? How does this affect me?

3. Exposure to "germs," especially at a young age, is important in developing the immune system.

Section 1.2.3

1. Economic hardship – let companies continue polluting to provide jobs

2. Everyone eventually dies. Everyone has a reason for living.

3. Communication gap? Some people have limited exposure to pets? Hierarchy with people at the top? Suffering isn't as great? (Similar concept applies to prosecution of animal abuse cases – with some atrocious acts being committed with minor punishment compared to if the act was committed on a human)

Section 1.2.4

1. Toxicity. Minor nutrient.

2. Where is the contamination and in what levels? What levels are dangerous? Is the contamination contained where it is or does it need to be removed or treated? How can it be removed or treated so that risks are minimized?

3. Yes, it's possible for something to be beneficial to human health at low doses but detrimental at high doses—e.g., salt, fat, minor nutrients, alcohol. Depending on levels, water is necessary for life so low doses are bad but extremely high doses can dilute the blood chemistry. (See http://info.med.yale.edu/caim/umd/chemsafe/references/dose.html. Per Paracelsus (1493 - 1541), "All substances are poisons; there is none which is not a poison. The right dose differentiates a poison.")

Section 1.2.5

1. An infectious agent killed the Martians. None of the technological solutions worked.

2. Romanticized. Novels, movies, plays, etc. are entertainment – idealized conditions. We don't want to be hit with the nitty gritty realities.

3. When building with brick, building a larger sewer would be easier than a small sewer. Many old city sewers are very large diameter and built out of brick. The engineers won out.

Section 1.2.6

1. Typically, most waste is landfilled. Some might be incinerated commercially; some might be burned by citizens. Recycling is also popular in many areas. Some might also wind up as litter or be illegally dumped. While technically not a waste if reused, some "waste" is donated to charities, families, and friends and some is sold in second-hand stores, flea markets, and yard sales.

2. MSW is considered by law to not be a hazardous waste or material. However, it contains many items that can be hazardous, such as batteries and cleaning fluids; these items are known as household hazardous waste. Some areas have permanent collection sites for these materials; some areas have specific collection days. Some states ban certain materials from landfills, such as batteries. These materials are collected by suppliers, i.e., an auto repair shop.

3. Government has the responsibility to look at the big picture. However, states and individuals have certain rights as well.

Section 1.3

1. Its ability to replace other materials, e.g., fertilizers. Technology, end use, economics.

2. Energy use, footprint. Consider methods to reduce energy use; make use of kinetic energy of flowing water; consider alternative disinfectants; consider source control and conservation efforts to reduce the amount of drinking water required and the amount of wastewater generated; integrate recycling water and waste materials into designs; increase use of rainwater harvesting and stormwater reuse.

Chapter 2

2-1. Total pipe cost = (\$/ft) (15 mi) (5280 ft/mi)
Total capital cost = (total pipe cost) + (pumping station capital cost)
Annual capital cost (principal + interest) = (total capital cost) (C_R)
C_R = capital recovery factor = 0.10185 for 20 y at 8%
Total annual cost = (annual capital cost) + (annual power cost)

Pipe Diameter (in)	Total Pipe Cost (\$)	Pumping Station Capital Cost (\$)	Total Capital Cost (\$)	Annual Capital Cost (\$/y)	Annual Power Cost (\$/y)	Total Annual Cost (\$/y)
8	396,000	150,000	546,000	55,610	10,000	65,610
10	633,600	145,000	778,600	79,300	8,000	87,300
12	950,400	140,000	1,090,400	111,057	7,000	118,057
16	1,108,800	120,000	1,228,800	125,153	6,000	131,153

(a) On the basis of total annual cost, the cheapest alternative is the 8-in pipe at \$65,610/y. One would have to assume that the 8-in pipe would have adequate capacity for the projected needs over the expected life of the system.

(b) Hedonistic ethics require maximizing personal pleasure. The engineer would recommend the 16-in pipe as the total capital cost, \$1,228,800, is the highest.

2-2. (a) Current waste disposal cost = \$1,200,000/y

Proposed waste disposal cost = (annual capital cost) + (annual operation cost) + (rent)

Annual capital cost = (capital cost) (C_R) = (\$800,000) (0.10185) = \$81,480/y
Proposed waste disposal cost = (\$81,480/y) + (\$150,000/y) + (\$200,000/y) = \$431,480/y

For the power company, the proposed waste disposal method is a good deal; it saves them \$768,520/y.

2-3. B/C ratios can be done with either annual costs or present worth costs. The only criterion is that all the costs have to be in the same units (i.e., either \$ or \$/y).

Benefits:
Annual benefits = (\$5.00/wk) (52 wk/y) = \$260/y
Present worth of benefits = (annual benefit) (C_P) = (\$260/y) (1.8333) = \$476.66

Costs:
Annual costs = (operating cost) + (capital cost) (C_R)
= (\$1.50/wk) (52 wk/y) + (\$4.00 + \$0.50) (0.54544) = \$80.45/y

Present worth of costs = (capital costs) + (operating cost) (C_P)
= (\$4.00 + \$0.50) + (\$1.50/wk) (52 wk/y) (1.8333) = \$147.50

$$B/C = \frac{\$260/yr}{\$80.45/yr} = \frac{\$476.66}{\$147.50} = 3.2$$

Because the B/C ratio is greater than 1, you should build the birdhouse.

2-4. Some items to consider…(1) Defense: collect data to determine potential effects in current and future uses for the stream and (2) Definition of pollution: What is unreasonable? What is a beneficial use? Who decides?

2-5. Some items to consider…Personal ethics, professional ethics, societal morals, public relations, B/C or other economic analysis

2-6. Some items to consider…Personal ethics, societal morals, effects on ecosystem and on vehicle, potential accidents caused

2-8. Original estimates:

Estimated construction cost = \$1.5 mil
Estimated benefit = \$2 mil
B/C = 1.3
Decision = build

Actual costs:

Actual construction cost = \$3 mil
Estimated benefit = \$2 mil
B/C = 0.7
Decision = do not build

Sunk cost method:

Assume sunk costs = \$1 mil
Additional construction cost = \$3 mil – \$1 mil = \$2 mill
Estimated benefit = \$2 mil
B/C = 1
Decision = break-even, build

2-12. For the environmental effects of deicers, see, for example, Michigan DOT's research on deicer effects and mitigating measures.

2-13. Capital costs – including permits and potential delays, operating costs – including pollution control and waste management, safety/insurance issues, public relations, potential future regulations, potential supply issues

2-14. (a) The calculation can be done on present worth or annual costs.

Cost	Option	
	Holding Basin	Plant Expansion
Expected life (y)	20	10
C_R at 6%	0.08719	0.13587
C_P at 6%	11.469	7.3600
Capital		
$ million	1.8	1.5
$/y	156,942	203,805
Operating		
$/y	100,000	400,000
$ million	1.1469	2.944
Total Present Worth ($ million)	2.9469	4.444
Total Annual ($/y)	256,942	603,805

On the basis of economics alone, the holding basin is cheaper, so it is the better choice.

(b) Some items to consider…Future regulations, other reasons to expand, public relations, current and immediate future economy, grant funds available

2-15. Some items to consider…Personal and professional ethics

2-16. (a) Lifetime risk = (average daily dose) (potency factor)

$$= \frac{(100 \text{ g apple})\left(\frac{1\times10^{-6} \text{ g heptachlor}}{\text{g apple}}\right)\left(\frac{10^{3} \text{ mg}}{\text{g}}\right)}{(70 \text{ kg})(70 \text{ yr})\left(365\frac{\text{d}}{\text{yr}}\right)\left(3.4\frac{\text{mg}}{\text{kg - d}}\right)} = 0.2 \times 10^{-6}$$

Additional risk = (population) (lifetime risk) = (100,000) (0.2×10^{-6}) = 0.02 cancer cases

(b) ignoring all effects associated with prenatal and childhood consumption, assuming healthy individuals, assuming no gender differences

2-20. The current generation rate could be estimated through standard methods of collecting and analyzing solid waste generation, including obtaining local haulers' records or sampling the solid waste. If there is not time for this type of data collection and analysis, then the engineer can obtain information from the state; this data is typically broken down by regions of the state. National averages should not be used except for very preliminary calculations. Compaction rates for collection vehicles can be obtained from vendors, haulers, or possibly disposal sites (e.g., landfills).

2-21. This question deals with total cost analysis (or total cost assessment). The engineer, to make the best decision, needs data such as the operating and maintenance costs of the vehicles, how much pollution the vehicles will cause during operation (e.g., fuel efficiency, oil changes, and tire wear), how much pollution was caused by their production, as well as their lifespans and the options and associated costs at the end of their useful lives (e.g., disposal or recycling).

2-22. Chris needs to explain the rationale behind the choice of the maintenance costs. It is not realistic to assume that the maintenance costs will be constant over the life of the vehicle. Typically, these costs increase with time, and they may not increase at the same rate for both vehicles. A type of sensitivity analysis could be conducted to determine the importance of the maintenance cost estimate by calculating either the annual cost or present worth as a function of different maintenance cost estimates. This information can be plotted and analyzed.

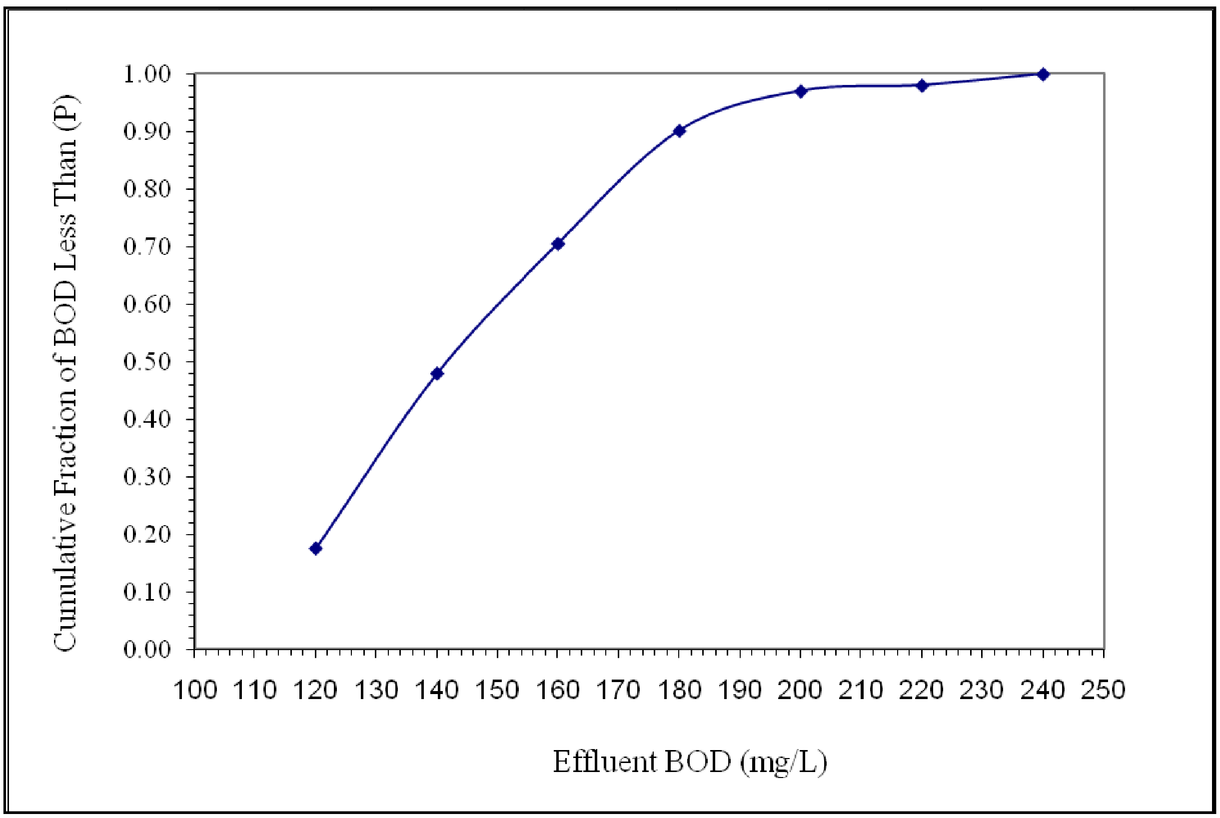
The capital cost can be reasonably estimated. The fuel/oil costs will fluctuate based on the market over the life of the vehicle, but the assumption can be made that the fluctuation will be the same for both analyses and, therefore, can be neglected if the vehicles have the same fuel efficiency. Similarly, inflation/deflation can be assumed to have no effect on the outcome of the analysis.

2-24. Health effects from increased air pollution (note that burning rubbish will contribute different pollutants than vehicle exhaust), effects on acid rain generation, smog formation, potential for fires spreading or people being hurt when burning

Chapter 3

3-1. Use grouped data analysis. Determine the average BOD for each range. Normalize the number of samples in each group by dividing by the total number of samples (102) to obtain the fractional probability. Using probability paper, plot fractional probability versus BOD (mg/L). (Note that equating the weighted mean (which is 155) with the median, P_{50}, assumes a symmetric distribution; the distribution is actually right skewed.)

BOD Range (mg/L)	Mean (mg/L)	No. of Samples r	$\sum r$	$P = (\sum r)/n$
110 - 129	120	18	18	0.176
130 - 149	140	31	49	0.480
150 - 169	160	23	72	0.706
170 - 189	180	20	92	0.902
190 - 209	200	7	99	0.971
210 - 229	220	1	100	0.980
230 - 249	240	2	102	1.000



(a) P_{10} = 112 mg/L
(b) P_{50} = 142 mg/L
(c) P_{95} = 195 mg/L

3-2. Use the coefficient of variation, C_v = (mean)/(standard deviation), to determine the most variable rainfall.

City	Annual Rainfall		C_v (%)
	x_{avg} (in/y)	s (in/y)	
Cheyenne	14.61	3.61	24.7
Pueblo	11.51	5.29	45.9
Kansas City	36.10	6.64	18.4

(a) Pueblo has the most variable rainfall.

(b) Use probability paper to plot probability values versus rainfall (next page). From the graph, determine the fractional probability (x) that rainfall will be less than 20 in/y for each city. Then the probability that rainfall will exceed 20 in/y is 1 – x. Multiply this fraction by 50 y to determine how many of the next 50 y will have rainfall exceeding 20 in.

Cheyenne: P(x < 20) = 0.94 (1 – 0.94)(50 yr) = 3 yr
Pueblo: P(x < 20) = 0.945 (1 – 0.945)(50 yr) = 2.8 yr (between 2 and 3 years)
Kansas City: P(x < 20) = 0.005 (1 – 0.005)(50 yr) = 49.8 yr (almost every year)

(c) Similarly,

Cheyenne: P(x < 12) = 0.22 (0.22)(50 yr) = 11 yr
Pueblo: P(x < 12) = 0.56 (0.56)(50 yr) = 28 yr
Kansas City: P(x < 12) < 0.0001 (0.0001)(50 yr) = 0.005 yr (essentially zero)

(d) 36.1 in. is the mean for Kansas City. The probability of it being exceeded is 0.50 or 50%.