Solutions Manual (version 2) for:

Environmental Engineering: Fundamentals, Sustainability, Design

John Wiley & Sons, 2014. (James R. Mihelcic & Julie B. Zimmerman)
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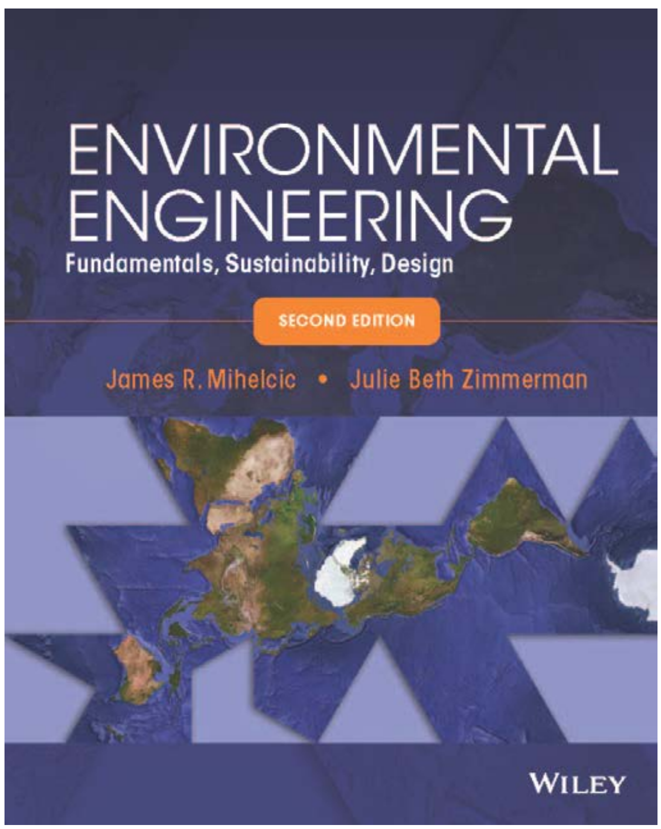

Version 2; June 4, 2014

Chapter 1. Sustainable Design, Engineering, and Innovation

1.1 Write an official 1-page office memo to your instructor that provides definitions for: (a) Sustainable Development (by the Bruntland Commission), (b) Sustainability (according to the American Academy of Environmental Engineers and Scientists (AAEES) Body of Knowledge), (c) Sustainability (according to the American Society of Civil Engineers (ASCE) Body of Knowledge), and, (d) Sustainable Development (according to the National Society of Professional Engineers (NSPE) Code of Ethics).

Solution:

Student responses will vary. See the next page for a full example memo.

Date: February 10, 2010
To: James R. Mihelcic, Civil & Environmental Engineering
Subject: Definitions of Sustainable Development

The Bruntland Commission defines **sustainable development** as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[1]
The American Society of Civil Engineers (ASCE) Body of Knowledge defines **sustainability** as "the ability to meet human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and enhancing environmental quality and the natural resource base essential for the future."[2]

The American Academy of Environmental Engineers (AAEE) Body of Knowledge defines **sustainability** as "a condition in which the use of natural resources and cycles in human and industrial systems does not lead to diminished quality of life due either to losses in future economic opportunities or to adverse impacts on social conditions, human health and the environment."[3] This definition is based on that of Mihelcic et al. (2003).[4]

The National Society of Professional Engineers (NSPE) defines **sustainable development** as "the challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environmental quality and the natural resource base essential for future development".[5]

All these definitions are similar to the broadest definition of sustainability by the Bruntland Commission . ASCE, AAEE, and NSPE definitions add more detail to the definition of development in relation to their respective fields with infrastructure and the environment. Between the three engineering societies, ASCE and NSPE are almost identical in defining sustainability as meeting human needs for engineering systems without compromising the future. However, the definition by AAEE is unique and incorporates quality of life as opposed to human needs, social conditions, and human health.

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[1] World Commission on Environment and Development. (1987). *Our common future.* Oxford: Oxford University Press.
[2] American Society of Civil Engineers. (2008). *Civil engineering body of knowledge for the 21st century, Preparing the civil engineer for the future*, (2nd. Ed.). Body of Knowledge Committee of the Committee on Academic Prerequisites for Professional Practice. Reston, VA.
[3] American Academy of Environmental Engineers. (2009). *Environmental engineering body of knowledge.* The Environmental Engineering Body of Knowledge Task Force, Baltimore, MD.

[4] Mihelcic, J.R., Crittenden, J.C., Small, M.J., Shonnard, D.R., Hokanson, D.R., Zhang, Q., Chen, H., Sorby, S.A., James, V.U., Sutherland, J.W., Schnoor, J.L. (2003). "Sustainability science and engineering: Emergence of a new metadiscipline," *Environmental Science & Technology*, 37(23):5314-5324.

[5] National Society of Professional Engineer. (2007). *Code of ethics for engineers*, Alexandria, VA.

1.2 Write your own definition of sustainable development as it applies to your engineering profession. Explain its appropriateness and applicability in 2-3 sentences.

Solution:

Student responses will vary.

1.3 Identify three definitions of sustainability from three sources (for example, local, state or federal government; industry; environmental organization; international organization; financial or investment organization). Compare and contrast those definitions with the Brundtland Commission definition. How do the definitions reflect their sources?

Solution:

Student responses will vary.

1.4 Relate the “Tragedy of the Commons” to a local environmental issue. Be specific on what you mean in terms of the “commons” for this particular example, and carefully explain how these “commons” are being damaged for current and future generations.

Solution:

Student responses will vary.

1.5 Research the progress that two countries of your choice (or your instructor's choice) have made in meeting each of the eight Millennium Development Goals (MDGs). Summarize the results in a table. Among other sources, you might consult the UN's MDG Web site, www.un.org/millenniumgoals/.

Solution:

The Millennium Development Indicator's website has country and regional snap shot tables for each of the goals and indicators (http://mdgs.un.org/unsd/mdg/Host.aspx?Content=Data/snapshots.htm). A summary of the progress made in Mali and Ghana (in 2013) (Students may have chosen different countries and results are updated on the web site) are displayed in the table below.

		Mali					Ghana				
		First Year		Latest Year			First Year		Latest Year		
Target	**Indicator**	*Value*	*Year*	*Value*	*Year*	**Progress**	*Value*	*Year*	*Value*	*Year*	**Progress**
Goal 1: Eradicate Extreme Poverty and Hunger											
Reduce extreme poverty by half	Proportion of population living below $1.25 (PPP) per day (%)	86.1	1994	50.4	2010	On track	51.1	1992	28.6	2006	On track
Reduce hunger by half	Proportion of population below minimum level of dietary energy consumption (%)	25.3	1991	7.9	2011	Achieved	40.5	1991	<5	2011	Achieved
Goal 2: Achieve Universal Primary Education											
Universal primary schooling	Net enrolment ratio in primary education (enrollees per 100 children)	42.2	1999	67.2	2011	On track	61.5	1999	84.2	2011	Below target
Goal 3: Promote Gender Equality and Empower Women											
Equal girls' enrolment in primary school	Ratio of girls to boys in primary education	0.61	1991	0.88	2011	Below target	0.86	1991	1	2011	Achieved
Women's share of paid employment	Share of women in wage employment in the non-agricultural sector (%)	27.3	1997	34.6	2004	Below target			31.7	2000	Below target
Women's equal representation in national parliaments	Proportion of seats held by women in national parliament (single or lower house only-%)	2.3	1997	10.2	2012	Off track	9	1998	8.3	2012	Off track

		Mali					Ghana				
		First Year		**Latest Year**			**First Year**		**Latest Year**		
Target	**Indicator**	*Value*	*Year*	*Value*	*Year*	**Progress**	*Value*	*Year*	*Value*	*Year*	**Progress**
Goal 4: Reduce child mortality											
Reduce mortality of under-five-year-old by two thirds	Under-five mortality rate (deaths of children per 1,000 births)	257	1990	175.6	2011	Off track	121	1990	77.6	2011	Below target
Goal 5: Improve maternal health											
Reduce maternal morality by three quarters	Maternal mortality ratio (maternal deaths per 100,000 live births)	1100	1990	540	2010	Off track	580	1990	350	2010	Off track
Access to universal reproductive health	Contraceptive prevalence rate (percentage of women aged 15-49, married or in union, using contraception)	6.7	1996	8.2	2006	Off track	17.2	1992	23.5	2008	Off track
	Unmet need for family planning (percentage of women aged 15-49, married or in union, with unmet need for family planning)	27.5	1996	27.6	2006	Off track	36.9	1993	35.7	2008	Off track
Goal 6: Combat HIV/AIDS, malaria and other diseases											
Halt and begin to reverse the spread of HIV/AIDs	HIV incidence rate (number of new HIV infections per year per 100 people aged 15-49)	0.09	2001	0.06	2009	Below target	0.18	2001	0.15	2009	Off track
Halt and begin to reverse spread of tuberculosis	Incidence rate and death rate associated with tuberculosis	163 /41	1990	68/9.7	2010	On track	155/ 36	1990	86/8.7	2010	On track

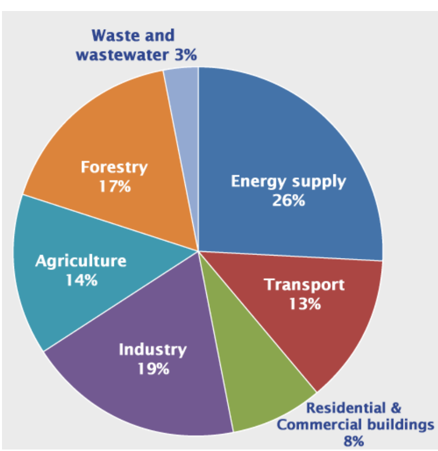
Target	Indicator	Mali First Year Value	Mali First Year Year	Mali Latest Year Value	Mali Latest Year Year	Mali Progress	Ghana First Year Value	Ghana First Year Year	Ghana Latest Year Value	Ghana Latest Year Year	Ghana Progress
Goal 7: Ensure environmental sustainability											
Reverse loss of forests	Proportion of land area covered by forest (%)	11.5	1990	10.2	2010	Below target	32.7	1990	21.7	2010	Below target
Halve proportion without improved drinking water	Proportion of population using an improved drinking water source (%)	28	1990	64	2010	Achieved	53	1990	86	2010	On track
Halve proportion without sanitation	Proportion of population using an improved sanitation facility (%)	15	1990	22	2010	Off track	7	1990	14	2010	Off track
Improve the lives of slum-dwellers	Proportion of urban population living in slums (%)	94.2	1990	65.9	2009	Below target	65.5	1990	40.1	2009	Below target
Goal 8: Develop a global partnership for development											
Internet users	Internet users per 100 in habitants	0	1990	2	2011	Off track	0	1990	14.1	2011	Below target

1.6 Go to the U.S Department of Energy's website (www.doe.gov), and research energy consumption in the household, commercial, industrial, and transportation sectors. Develop a table on how this specific energy consumption relates to the percent of U.S. and global CO_2 emissions. Identify a sustainable solution for each sector that would reduce energy use and CO_2 emissions.

Solution:

Students will need to do some research on the web for this item. Energy consumption values can be found on the Annual Energy Review website (http://www.eia.gov/totalenergy/data/annual/index.cfm) . Greenhouse gas emissions by sector can be found on the EPA (http://www.epa.gov/climatechange/ghgemissions/global.html) or IPPC web pages.

Sector	**Total U.S. Energy Consumption in 2012 (trillion Btu)**	**Percent of U.S. Emissions (2012)**	**Percent Global Emissions (2004)**	**Sustainable Solution (Students answers may vary)**
Household	20,195	21.3%	8% (includes household & commercial	Solar panels
Commercial	17,507	18.4%	(see above)	LED light fixtures
Industrial	30,562	32.2%	19%	Carbon tax
Transportation	26,712	28.1%	13%	Public transportation infrastructure
Total	94,977	100%	See figure below for more details	



Global greenhouse gas emissions by source (commercial and residential are grouped) (EPA reference to IPCC 2007 for global emissions in 2004)

1.7 As a consumer interested in reducing your carbon emissions, (a) which should you do: (1) install more efficient lighting for your home or (2) buy a car that gets higher miles per gallon? To answer this, consider that a 100W light bulb that is run 3 hours a day every day will use around 100 kWh a year. A high efficiency light uses about 25% of a conventional light bulb. Replacing it with a 25W Compact Fluorescent Bulb would save 75 kWh a year. This would equal 150 lbs of carbon dioxide or the same amount of carbon dioxide emissions associated with burning 7.5 gallons of gasoline. (b) Given that the average US household uses 10,000 kWh a year of which 8.8% is lighting, how many gallons of gas and lbs of CO2 could be saved by switching all of the bulbs in a home? (c) For comparison, if you drove 12,000 miles a year and upgraded from a car that gets the national average of 20 mpg to one that got 30 mpg, how much would you reduce your gas consumption and CO2 emissions on an annual basis? (d) What if you upgraded from a car that gets 30 mpg to 37 mpg? (combustion of 100 gallons of gasoline releases 2,000 lbs. of carbon dioxide).

Solution:

a. You would choose an answer depending on your house, your lighting habits, your type of car and how you use it. You could ask questions like how many light bulbs you use in your home and for how long each day and how much you drive each year. In fact, the average US consumer would save a little more energy and CO2 emissions by upgrading their card.

b.

$$10{,}000 kWh \times 0.088 \times 0.75 \times \frac{150\ lbs\ CO_2}{75\ kWh} = \mathbf{1,320\ lbs\ CO_2\ savings}$$

$$10{,}000 kWh \times 0.088 \times 0.75 \times \frac{7.5\ gallons}{75\ kWh} = \mathbf{66\ gallons\ gas\ savings}$$

c.

$$(12{,}000\ miles \times \frac{1\ gallon}{20\ miles}) - (12{,}000\ miles \times \frac{1\ gallon}{30\ miles}) = \mathbf{200\ gallons}$$

$$200\ gallons \times \frac{2{,}000\ lbs\ CO_2}{1000\ gallons} = \mathbf{400\ lbs\ CO_2}$$

d. Switching from a 30 mpg vehicle to 37 mpg vehicle results in a 10 mpg savings.

$$(12{,}000\ miles \times \frac{1\ gallon}{30\ miles}) - (12{,}000\ miles \times \frac{1\ gallon}{37\ miles}) = \mathbf{76\ gallons}$$

$$76\ gallons \times \frac{2{,}000\ lbs\ CO_2}{100\ gallons} = \mathbf{1,520\ lbs\ CO_2/yr}$$

1.8 Visit EPA's Presidential Green Chemistry Challenge Award website at www.epa.gov/greenchemistry/pubs/pgcc/past.html. Select a past award-winning project. Based on the description of this project, what are the environmental, economic and social benefits of this green chemistry advance?

Solution:

Student responses will vary. An example of an award-winning project of the Green Chemistry Challenge Award is for Buckman's Maximyze Enzymes. These enzymes are made of natural catalysts that reduce the energy and wood fiber needed to manufacture high-quality paper. In one case, paper was able to be reduced by 3 pounds per 1,000 square feet which not only reduces the amount of raw pulp materials but also lowers shipping and energy costs. With increased paper strength, more recycled fibers can be used in the paper which is beneficial to the environment and reduces costs. Overall, this new enzyme translates into a social benefit with less deforestation and a cleaner environment for a healthier society. For more information on this specific green chemistry challenge award winning project, see the link below:

http://www.buckman.com/about-us/news/562-buckman-wins-presidential-green-chemistry-challenge-award

1.9 Discuss whether shoe A (leather) or shoe B (synthetic) is better for the environment based on the data in Table 1.8. Is it possible to weight one aspect (air, water, land pollution or solid waste) as being more important than another? How? Why? Who makes these decisions for our society?

Table/1.8 Hypothetical Life Cycle Environmental Impacts of Shoes on a basis of per 100 pairs of shoes produced

Product	Energy use (BTU)	Raw material consumption	Water use (gallons)	Air pollution (lbs.)	Water pollution	Hazardous and solid waste
Shoe A (leather)	1	Limited supply; some renewable	2	4	2 lb. organic chemicals	2 lb. hazardous sludge
Shoe B (synthetic)	2	Large supply; not renewable	4	1	8 lb. inert inorganic chemicals	1 lb. hazardous sludge; 3 lb. nonhazardous sludge

Solution:

Student responses will vary.

While shoe A uses less energy, nonrenewable resources and water, it uses more water and results in higher hazardous and solid waste. On the other hand Shoe B uses more energy and water but emits less air pollution and produces less hazardous and solid waste. You will need to develop a weighting system to rate each option, in each environmental impact category to develop an overall score to compare the two options. Environmental regulators and the general population make these decisions for society.

1.10 To compare plastic and paper bags in terms of acquisition of raw materials, manufacturing and processing, use and disposal, we'll use data provided by Franklin Associates, a nationally known consulting firm whose clients include the U.S. Environmental Protection Agency as well as many companies and industry groups. In 1990, Franklin Associates compared plastic bags to paper bags in terms of their energy and air/water emissions in manufacture, use, and disposal. Table 1.9 presents the results of their study:

Table/1.9 Results of Study Comparing Plastic and Paper Bags

Life Cycle Stages	Air Emissions (pollutants) oz/bag		Energy Required BTU/bag	
	Paper	Plastic	Paper	Plastic
Materials manufacture, product manufacture, product use	0.0516	0.0146	905	464
Raw materials acquisition, product disposal	0.0510	0.0045	724	185

(a)Which bag would you choose if you were most concerned about air pollution? (Note that the information does not tell you if these are toxic air emissions or greenhouse gas emissions) (b) If you assume that two plastic bags equal one paper bag, does the choice change? (c) Compare the energy required to produce each bag. Which bag takes less energy to produce?

Solution:

a) For paper: 0.0516 + 0.0510 = 0.1026 oz/bag
For plastic: 0.0146 + 0.0045 = 0.0191 oz/bag

Plastic; however, the nature of the air emissions may be of concern.

b) For paper: 0.0516 + 0.0510 = 0.1026 oz/bag
For plastic: (0.0146 + 0.0045) * 2 = 0.0382 oz/bag

No. Plastic still has a lower life cycle air emissions than paper even with using twice as many bags.

c) For paper = 905 + 724 = 1629 BTU/bag
For plastic = 464 + 185 = 649 BTU/bag

Plastic bags take less energy to produce (even at the 2:1 ratio).

1.11 You are preparing a life cycle analysis of three different electrification options for powering your 1,200 square foot home in rural Connecticut. The options you're considering include: 1) just using your local grid, 2) putting in a solar installation on your roof, or 3) building a transmission extension to join up with your neighbor's already-built wind turbine. Write a possible goal, scope, function, and functional unit for this LCA. Explain your reasoning.

Solution:

Student's answers may vary.

Goal: Determine which of the following electrification options have the least environmental impact: 1) just using your local grid, 2) putting in a solar installation on your roof, or 3) building a transmission extension to join up with your neighbor's already-built wind turbine.

Scope: This LCA will consider the resource extraction, manufacturing, and use-phase but will not consider transportation and end-of-life stage.

Function: Provide enough energy to light and run appliances in a 1,200 square foot home in rural Connecticut.

Functional unit: The energy to power a 1,200 square foot home in rural Connecticut.

1.12 Consider the full life cycle of each of the three electrification options (possibly beyond whatever you've selected for the scope of your LCA) in Problem 1.11. Discuss which of the life cycle stages is most impactful for each electrification type. You will need to take into account the life cycle impacts of primary through final energy in each case. As a reminder, life cycle stages typically include: resource extraction, manufacture, transportation, use, and end of life.

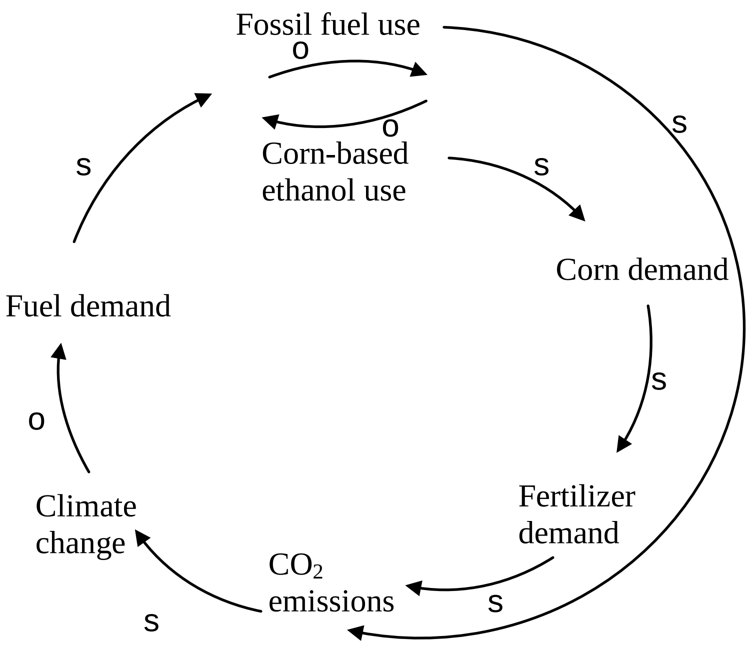
Solution:

Student responses will vary but below is an example solution.

Electrification Option	**Impactful life stage**
1) Just using your local grid	Material extraction of non-renewable resource such as coal and the burning of such during the use-phase.
2) Putting in a solar installation on your roof	Material extraction of metals for solar panels. End-of-use in recycling/disposal of solar panels.
3) Building a transmission extension to join up with your neighbor's already-built wind turbine	Material extraction for materials to build the extension.

1.13 Draw causal loop diagram for corn-based ethanol production using the following variables: climate change, corn-based ethanol use, fertilizer demand, CO_2 emissions, Fuel demand, Fossil fuel use, and Corn demand.

Solution:



1.14 (a) Is centralized drinking water treatment and distribution more or less resilient than point of use water treatment technologies? Why or why not? (b) Does it matter whether these water treatment systems are implemented in the developing or developed world?

Solution:

Student responses will vary.

1.15 The design team for a building project was formed at your company last week and they have already held two meetings. Why is it so important for you to get involved immediately in the design process?

Solution:

It is at the design stage where there is the most power and potential to influence the ultimate "greenness" or sustainability of a design. It is at this stage that there is an ability to specify inherently benign materials, to design for end of life handling, and consider the entire life cycle. At the design stage there is an opportunity to impart new performance and capabilities. This is also the most economical place to focus due to the fact that costs are committed at this point although they are not incurred until much later in the process.

1.16 Provide an example of a product either commercially available or currently under development that uses biomimicry as the basis for its design. Explain how the design is mimicking a product, process, or system found in nature.

Solution:

Student responses will vary.

1.17 Two reactants, benzyl alcohol and tosyl chloride, react in the presence of an auxiliary, triethylamine, and the solvent toluene to produce the product sulfonate ester (see Table 1.10). Calculate the E factor for the reaction. What would happen to the E factor if the solvents and auxiliary chemicals were included in the calculation? Should these types of materials and chemicals be included in an efficiency measure? Why or why not?

Table 1.10. Useful information needed to solve Problem 1.17

Reactant	Benzyl alcohol	10.81 g	0.10 mole	MW 108.1 g/mole
Reactant	Tosyl chloride	21.9 g	0.115 mole	MW 190.65 g/mole
Solvent	Toluene	500 g		
Auxiliary	Triethylamine	15 g		MW 101 g/mole
Product	Sulfonate ester	23.6 g	0.09 mole	MW 262.29 g/mole

Solution:

Without solvent:

$$E-\ factor=\frac{(10.81+21.9)}{23.6}=1.4$$

$$\Rightarrow \boxed{\text{1.4 kg waste produced / kg of product}}$$

With solvent and auxiliary:

$$E-\ factor=\frac{(10.81+21.9+500+15)}{23.6}=23.2$$

$$\Rightarrow \boxed{\text{23.2 kg waste produced / kg of product}}$$

If solvents and auxiliary chemicals are included the E factor increases 20-fold. <u>These chemicals should be included if they are not recovered and recycled because they also contribute to the total waste of the process. </u>These chemicals are also important because many solvents are VOCs and toxics.

1.18 Choose three of the principles of green engineering. For each one, (a) explain the principle in your own words; (b) find an example (commercially available or under development), and explain how it demonstrates the principle; and (c) describe the associated environmental, economic, and societal benefits, identifying which ones are tangible and which ones are intangible.

Solution:

Application 1.10 in Chapter 1 lists the twelve Principles of Green Engineering. Students can build their solution to this problem by reviewing this table and associated reading material.

1.19 (a) Develop five sustainability metrics or indicators for a corporation or an industrial sector analogous to those presented for communities in Table 1-4. (b) Compare them with traditional business metrics or indicators. (c) Describe what new information can be determined from the new sustainability metrics or indicators.

Solution:

Student responses will vary.

1.20 A car company has developed a new car, ecoCar, that gets 100 miles per gallon (mpg), but the cost is slightly higher than cars currently on the market. What type of incentives could the manufacturer offer or ask Congress to implement to encourage customers to buy the new ecoCar?

Solution:

Students' responses will vary. Here is an example response:

First, the manufacturer would need to demonstrate how a higher capital cost of the vehicle will be made up in the savings with higher fuel efficiency. The manufacturer could also offer better warranties or payment plans for the vehicle to attract consumers. They may request that congress provide tax write offs or subsidies for consumers who buy more fuel efficient vehicles. Moreover, the manufacturer could lobby for tax breaks on their ecoCar facility property taxes and revenue. Those savings could then reduce the market price of the vehicle for consumers.

1.21 Do you agree or disagree with the following statement? Why or why not? (3-5 sentences) “Technology-forcing pollution regulations are preferable to standards- or outcome-based regulations”.

Solution:

Student responses will vary.

1.22 You are about to buy a car that will last 7 years before you have to buy a new one, and Congress has just passed a new tax on greenhouse gases. Assume a 5% annual interest rate. You have two options: (a) Purchase a used car for $12,000, upgrade the catalytic converter at a cost of $1,000, and pay a $500 annual carbon tax. This car has a salvage value of $2,000. (b) Purchase a new car for $16,500 and pay only $100 annually in carbon tax. This car has a salvage value of $4,500. Based on the annualized cost of these two options, which car would you buy?

Solution:

a. $PV = 13{,}000 + \frac{500}{1.05} + \frac{500}{1.05^2} + \cdots + \frac{500-2{,}000}{1.05^7} = \$14{,}472 A = 14{,}472\left(\frac{0.05}{1-(1+i)^{-7}}\right) = \$\mathbf{2,501}$

b. $PV = 16{,}600 + \frac{500}{1.05} + \frac{500}{1.05^2} + \cdots + \frac{500-4{,}500}{1.05^7} = \$13{,}881 A = 13{,}881\left(\frac{0.05}{1-(1+i)^{-7}}\right) = \$\mathbf{2,399}$

Chapter 2. Environmental Measurements

2.1 (a) During drinking water treatment, 17 lb. of chlorine (Cl) are added daily to disinfect 5 million gallons of water. What is the aqueous concentration of chlorine in mg/L? (b) The *chlorine demand* is the concentration of chlorine used during disinfection. The *chlorine residual* is the concentration of chlorine that remains after treatment so the water maintains its disinfecting power in the distribution system. If the residual concentration is 0.20 mg/L, what is the chlorine demand in mg/L?

Solution:

a) 17 lb. chlorine added to 5 million gallons of water. Chlorine dosage in mg/L:

$$\frac{17\ lb/day}{5\times10^{6}\ gal/day}\times\frac{454\ g}{1\ lb}\times\frac{1000\ mg}{1 g}\times\frac{1\ gal}{3.78\ L}=\boxed{0.41\ mg/L}$$

b) Chlorine demand:

$$0.41\ mg/L-0.20\ mg/L=\boxed{0.21\ mg/L}$$

2.2 A water sample contains 10 mg NO_3^-/L. What is the concentration in (a) ppm_m, (b) moles/L, (c) mg NO_3^--N/L, and (d) ppb_m?

Solution:

10 g NO_3^-/L in various units.

a) 1 L water = 1 kg water (in water, mg/L = ppm)

$$\frac{10\ mg/L}{1\ kg/L} = \boxed{10\ ppm\ as\ NO_3^-}$$

b) 62 grams NO_3^- = 1 mole NO_3^-

$$\frac{10\ mg}{L} \times \frac{1\ g}{1{,}000\ mg} \times \frac{1\ mole}{62\ g} = \boxed{1.6 \times 10^{-4}\ moles\ NO_3^-/L}$$

c) 62 grams NO_3^- = 1 mole NO_3^-; 14 grams N = 1 mole N; 1 mole NO_3^- = 1 mole N

$$\frac{10\ mg\ NO_3}{L} \times \frac{1\ mole\ NO_3}{62\ g\ NO_3} \times \frac{1\ mole\ N}{1\ mole\ NO_3} \times \frac{14\ g\ N}{1\ mole\ N} = \boxed{2.3\ mg\ \mathrm{NO_3\text{-}N/L}}$$

d) 1 L water = 1 kg water; 1 kg = 10^6 mg; 1 billion = 10^3 million

$$\frac{10\ mg/L}{1\ kg/L} \times \frac{1000\ million}{1\ billion} = \boxed{10{,}000\ ppb\ as\ NO_3^-}$$

2.3 A liquid sample has a concentration of iron (Fe) of 5.6 mg/L. The density of the liquid is 2,000 g/L. What is the Fe concentration in ppm_m?

Solution:

$$2000\ g = 2\ kg$$

$$\frac{5.6\,\frac{mg}{L}}{2.0\,\frac{kg}{L}} = \mathbf{2.8\ ppm_m}$$

2.4 Coliform bacteria (for example, *E. coli)* are excreted in large numbers in human and animal feces. Water that meets a standard of less than one coliform per 100 mL is considered safe for human consumption. Is a 1 L water sample that contains 9 coliforms safe for human consumption?

Solution:

Standard requires < 1 coliform/100 mL, or 10 coliform/1 L

$$\frac{9\ coliforms}{L} \times \frac{L}{10\ coliforms\ (100\ mL)} = \boxed{0.9\ coliforms/100\ mL}$$

<u>This value is < 1 coliform/100 mL; therefore, water is safe.</u>

Solutions Manual prepared by: Colleen Naughton, Ziad Katirji, Heather E. Wright Wendel, and James Mihelcic
Environmental Engineering: Fundamentals, Sustainability, Design, 2nd Edition
James R. Mihelcic and Julie Beth Zimmerman, John Wiley & Sons, New York, 2014.

2.5 The treated effluent from a domestic wastewater-treatment plant contains ammonia (NH_3) at 9.0 mg N/L and nitrite (NO_2^-) at 0.5 mg N/L. Convert these concentrations to mg NH_3/L and mg NO_2^-/L.

Solution:

17 g NH_3 = 1 mole NH_3

46 g NO_2^- = 1 mole NO_2^-

1 mole N = 1 mole NH_3 = 1 mole NO_2^-

$$\frac{9.0\ mg\ NH_3 - N}{L} \times \frac{1\ mole\ N}{14\ g\ N} \times \frac{1\ mole\ NH_3}{1\ mole\ N} \times \frac{17\ g\ NH_3}{1\ mole\ NH_3} = \boxed{10.9\ mg\ NH_3 / L}$$

$$\frac{0.5\ mg\ NO_2 - N}{L} \times \frac{1\ mole\ N}{14\ g\ N} \times \frac{1\ mole\ NO_2}{1\ mole\ N} \times \frac{46\ g\ NO_2}{1\ mole\ NO_2} = \boxed{1.6\ mg\ NO_2 / L}$$

2.6 Nitrate concentrations exceeding 44.3 mg NO_3^-/L are a concern in drinking water due to the infant disease, methemoglobinemia. Nitrate concentrations near three rural wells were reported as 0.01 mg NO_3^- N/L, 1.3 mg NO_3^- N/L, and 20.0 mg NO_3^- N/L. Do any of these three wells exceed the 44.3 ppm_m level?

Solution:

Convert the regulatory value to units of "as N". Then compare to the measured concentrations.

$$\frac{44.3\ mg\ NO_3}{L} \times \frac{1\ mole\ NO_3}{62.0\ g\ NO_3} \times \frac{1\ mole\ N}{1\ mole\ NO_3} \times \frac{14.0\ g\ N}{1\ mole\ N} = 10.0\ mg\ NO_3 - N / L$$

<u>The third well (20.0 mg NO_3^--N/L) exceeds the 10 ppm level.</u>

2.7 Sulfate (SO_4^{2-}) concentration is 10 mg SO_4^{2-}/L and monohydrogen sulfide (HS^-) concentration is 2 mg HS^-/L. What is the total inorganic sulfur concentration in mg S/L?

Solution:

Convert Sulfate (SO_4^{2-}) to molarity and then use the molar concentration of sulfur to convert to the concentration of sulfur. Add together the concentration of sulfur from both sulfate (SO_4^{2-}) and monohydrogen sulfide (HS^-) to get the total inorganic sulfur concentration.

$$\frac{10\ mg\ \mathrm{SO_4}^{2-}}{L} \times \frac{1\ mole\ \mathrm{SO_4}^{2-}}{96.07\ g} \times \frac{1\ mole\ \mathrm{S}}{1\ mole\ \mathrm{SO_4}^{2-}} \times \frac{32.07\ g}{mole\ S} = \frac{3.34\ mg\ \mathrm{SO_4}^{2-} - \mathrm{S}}{L}$$

$$\frac{2\ mg\ \mathrm{HS}^-}{L} \times \frac{1\ mole\ \mathrm{HS}^-}{33.08\ g} \times \frac{1\ mole\ \mathrm{S}}{1\ mole\ \mathrm{HS}^-} \times \frac{32.07\ g}{mole\ S} = \frac{1.94\ mg\ \mathrm{HS}^- - \mathrm{S}}{L}$$

$$total\ sulfur\ concentration\ = 3.34\ + 1.94\ = \frac{\mathbf{5.28\ mg\ S}}{\boldsymbol{L}}$$

Solutions Manual prepared by: Colleen Naughton, Ziad Katirji, Heather E. Wright Wendel, and James Mihelcic
Environmental Engineering: Fundamentals, Sustainability, Design, 2nd Edition
James R. Mihelcic and Julie Beth Zimmerman, John Wiley & Sons, New York, 2014.

2.8 Suppose you must determine the amount of hydrogen halides (HCl, HBr and HF) in the flue gas leaving a chemical reactor. The emission sampling train for hydrogen halide determination calls for a total of 200 mL of 0.1 N H_2SO_4 as an absorbing solution. The absorbing solution will be located on the impingers of the sampling train. (a) How many grams of H_2SO_4 should be added to water to create 200 mL of a 0.1 N H_2SO_4 solution? (b) Calculate the molarity of the 0.1 N H_2SO_4 solution. (problem from EPA Air Pollution Training Institute, http://www.epa.gov/apti/bces/)

Solution:

a) $0.1\ \mathrm{N\ H_2SO_4} \times \frac{2\ \mathrm{eqv}}{\mathrm{mole}} \times \frac{1\ \mathrm{mol\ H_2SO_4}}{\mathrm{L}} \times \frac{98.07\mathrm{g}}{\mathrm{mol\ H_2SO_4}} \times \frac{1\ \mathrm{L}}{1000\ \mathrm{L}} \times 200\mathrm{ml}\ = \mathbf{3.9\ g}$

b) $0.1\ \mathrm{N\ H_2SO_4} \times \frac{2\ \mathrm{eqv}}{\mathrm{mole}} \times \frac{1\ \mathrm{mol\ H_2SO_4}}{\mathrm{L}} = 0.2 \frac{\mathrm{mol}}{\mathrm{L}}\ \mathrm{H_2SO_4}\ = \mathbf{0.2\ M\ H_2SO_4}$

2.9 The concentration of cadmium (Cd) in a liquid is known to be 130 ppm at 20°C. Calculate the total quantity of cadmium present in a one-gallon sample. The sample has a density of 62.4 lb/ft3. (problem from EPA Air Pollution Training Institute, http://www.epa.gov/apti/bces/)

Solution:

1 L water = 1 kg water (in water, mg/L = ppm). The density of water is 62.4 lb/ft^3

$$130\ ppm = 130\frac{mg}{L} \times \frac{3.7854\ L}{gal} = 492\frac{mg}{gal}$$
$$\boldsymbol{= 490\ mg\ or\ .490\ g\ Cd\ in\ a\ one - gallon\ sample}$$

2.10 As a quality control check, a sample of acetone is taken from a process to determine the concentration of suspended particulate matter. An 850-mL sample was placed in a beaker and evaporated. The remaining suspended solids were determined to have a mass of 0.001 gm. The specific gravity of acetone is 0.79 gm/cm^3. (a) Determine the concentration of the sample as mg/L. (b) Determine the concentration of the sample as ppm. (problem from EPA Air Pollution Training Institute, http://www.epa.gov/apti/bces/)

a)

$$Concentration = \frac{0.001g}{850\ mL} \times \frac{1000mL}{1\ L} \times \frac{1000\ mg}{1g} = \mathbf{1.2}\,\frac{\boldsymbol{mg}}{\boldsymbol{L}}$$

b)

$$Concentration = 0.079\frac{g}{cm^3} \times \frac{1\ cm^3}{1\ mL} \times \frac{1000L}{1\ L} \times \frac{1kg}{1000g} = 0.079\frac{kg}{L}$$

$$\frac{1.2\frac{mg}{L}}{0.079\frac{kg}{L}} = \mathbf{15}\ \boldsymbol{ppm_m}$$

2.11 A paper mill produces paper from wood pulp. Pulp production (at the pulp plant) begins with digesting the wood chips in a solution of sodium hydroxide and sodium sulfide. The sodium hydroxide is diluted with water (shown in the reaction below) prior to being sent to the digester.

$NaOH + H_2O \rightarrow Na^+ + OH^- + H_2O$

If 4 kg of sodium hydroxide is added for each 1000 L of water, determine the following: (a) the molarity of the resulting solution, (b) the normality of the resulting solution. (problem from EPA Air Pollution Training Institute, http://www.epa.gov/apti/bces/)

a) $\frac{4\ kg\mathrm{NaOH}}{1000L} \times \frac{10^6}{kg} \times \frac{1\ mole\ \mathrm{NaOH}}{39.99\ g\ \mathrm{NaOH}} \times \frac{1\ mole\ \mathrm{Na}^+}{1\ mole\ \mathrm{NaOH}} = 100\ \frac{mole\ \mathrm{Na}^+}{L} = \mathbf{100}\ \boldsymbol{M}\ \mathbf{Na^+}$

$$\frac{4\ kg\mathrm{NaOH}}{1000L} \times \frac{10^6}{kg} \times \frac{1\ mole\ \mathrm{NaOH}}{39.99\ g\ \mathrm{NaOH}} \times \frac{1\ mole\ \mathrm{OH}^-}{1\ mole\ \mathrm{NaOH}} = 100\ \frac{mole\ \mathrm{OH}^-}{L} = \mathbf{100}\ \boldsymbol{M}\ \mathbf{OH^-}$$

b)

$$100\ \frac{mole\ \mathrm{OH}^-}{L} \times \frac{1\ eqv}{mole} = \frac{100\ eqv}{mole} = \mathbf{100\ N\ OH^-}$$

$$100\ \frac{mole\ \mathrm{Na}^+}{L} \times \frac{1\ eqv}{mole} = \frac{100\ eqv}{mole} = \mathbf{100\ N\ Na^+}$$

2.12 In Florida, advanced wastewater treatment standards require that treated effluent have no more than 5 ppm BOD_5, 5 ppm TSS, 3 ppm total nitrogen (TN), and 1 ppm total phosphorus (TP). a) What is the wastewater standard for TN and TP in mg/L? b) If all of the nitrogen is transformed to nitrate during the advanced treatment, what is the effluent limit of nitrate in mg/L? c) If your laboratory had obtained and processed 200-mL sample of treated wastewater for the TSS test , how many mg of suspended solids were captured on the filter for this sample?

Solution:

a) 1 L water = 1 kg water (in water, mg/L = ppm)

$$3\ ppm\ \mathrm{TN} = \mathbf{3\frac{mg\ N}{L}}$$

$$1\ ppm\ \mathrm{TP} = \mathbf{1\frac{mg\ P}{L}}$$

b) $3\frac{mgN}{L} \times \frac{1\ mole\ N}{14.01\ g} \times \frac{1\ mole\ NO_3-}{1\ mole\ N} \times \frac{62\ g}{1\ mole\ NO_3-} = \mathbf{13}\ \boldsymbol{\frac{mgNO_3-}{L}}$

c) $5\ ppm\ \mathrm{TSS} = 5\frac{\mathrm{mg\ TSS}}{\mathrm{L}} \times 200\mathrm{L}\ = \mathbf{1,000\ mg\ suspended\ solids}$

2.13 Mirex (MW = 540) is a fully chlorinated organic pesticide that was manufactured to control fire ants. Due to its structure, mirex is very unreactive; thus, it persists in the environment. Lake Erie water samples have had mirex measured as high as 0.002 µg/L and lake trout samples with 0.002 µg/g. (a) In the water samples, what is the aqueous concentration of mirex in units of (i) ppb_m, (ii) ppt_m, (iii) µM? (b) In the fish samples, what is the concentration of mirex in (i) ppm_m, (ii) ppb_m?

Solution:

a) i) in dilute solutions µg/L = ppb, thus the concentration is 0.002 ppb_m

ii) 1,000 ppt = 1 ppb, therefor, the concentration is 2 ppt_m

iii)

$$\frac{0.002\ \mu g}{L} \times \frac{1\ mole}{540\ g} = \boxed{3.7 \times 10^{-6}\ \mu M}$$

b) i)

$$\frac{0.002\ \mu g}{g} = \boxed{0.002\ ppm}$$

ii) In solids, ppb = µg/kg

$$\frac{0.002\ \mu g}{g} \times \frac{1000\ million}{1\ billion} = \boxed{2\ ppb}$$