CHAPTER

8 Creativity and Innovation Examples From Various Engineering Specialties

We recognize that we cannot survive on meditation,
poems, and sunsets. We are restless.
We have the irresistible urge to dip our hands into the stuff
of the earth and do something with it.
—Samuel C. Florman, engineer and author

Objectives:

After studying this chapter, you will be able to:

- Use six engineering specialties to illustrate the diversity of creativity and innovation in the engineering profession
- Describe lessons learned from the creative/innovative cases
- Give examples of other opportunities to be creative and innovative
- Discuss the importance of engineering relative to many other professions

8.1 MORE EXAMPLES TO ENGAGE YOU

Now that you've studied twenty whole-brain methods in Chapters 4 and 7, you are likely to see their potential for helping you and teams you serve on be much more creative and innovative. Perhaps you are even anxious to use some of the tools to address real challenges—and of course you can, because each of us is surrounded, whether we are students or practitioners, by real engineering and other challenges.

Over eighty examples of creative/innovative approaches to technical and non-technical IPOs are at least briefly described in the preceding chapters of this book, as summarized in Table 5.1. Building on those examples and on your exposure to many whole-brain methods and as further support for your creative/innovative urges, this chapter presents a sampling of creative/innovative results drawn from widely varying engineering specialties in more depth.

Although I cannot usually link one or more of the whole-brain methods to the processes used in these examples, you can safely assume that the essentials of some of those tools were employed. The products and processes produced in each of the examples presented in this chapter clearly used the input of engineers, scientists, and others. However, for simplicity and because engineers are my primary audience, I am focusing on engineering specialties. For your benefit, each description concludes with a Lessons Learned section. The lessons relate mostly to creativity and innovation, but some also address wider realities of engineering practice.

8.2 AEROSPACE ENGINEERING: LANDING A ROVER ON MARS

Early in this century, a team of US National Aeronautics and Space Administration (NASA) engineers and scientists was challenged to transport a one-ton robot 352 million miles to Mars. Once it entered the Mars atmosphere, the robot, which would be called the Curiosity rover, was to be gently set down so that it could move about, gather images, monitor the environment, and drill into the planet's surface.

8.2.1 How They Did It

After nine years of persistent creative-innovative effort, which began with a three-day brainstorming session in 2003, they thought they knew how to meet the challenge and were ready to go. They were prepared to take Curiosity, the six-wheeled robot illustrated in Figure 8.1, to Mars.

The team's persistence, creativity, and innovation paid off. Curiosity began its work on Mars in August 2012. This is how the amazing feat was accomplished (Ouellette 2013, Wall 2012):

1. Beginning with a November 2011 blast off from Cape Canaveral, Florida, a rocket traveled for eight months at up to 13,200 miles per hour and took the payload to the Mars atmosphere.
2. The rocket ejected the space capsule, which carried landing gear with the robot attached to the landing gear's underside.
3. The capsule deployed a supersonic parachute that slowed the descent of the two components to two hundred miles per hour.
4. Bolts exploded, releasing the parachute, and then rockets on the landing gear fired to slow the descent to two miles per hour.
5. The landing gear/robot combination hovered sixty feet above Mars' surface while cables lowered the robot to the planet's surface. The landing gear, appropriately, was called the *sky crane*.

Figure 8.1
This artist's concept shows how the Curiosity rover might look as it explored Mars.
(SergeyDV/Shutterstock)

6. Cable cutters severed the cable links when, on August 2, 2012, the robot was safely on the Mars surface, and the landing gear moved away and intentionally crashed—its mission accomplished.
7. Curiosity went to work, as shown in the self-portrait in Figure 8.2, which is a mosaic of dozens of images taken in April and May 2014. The composite image does not show the rover's arm.

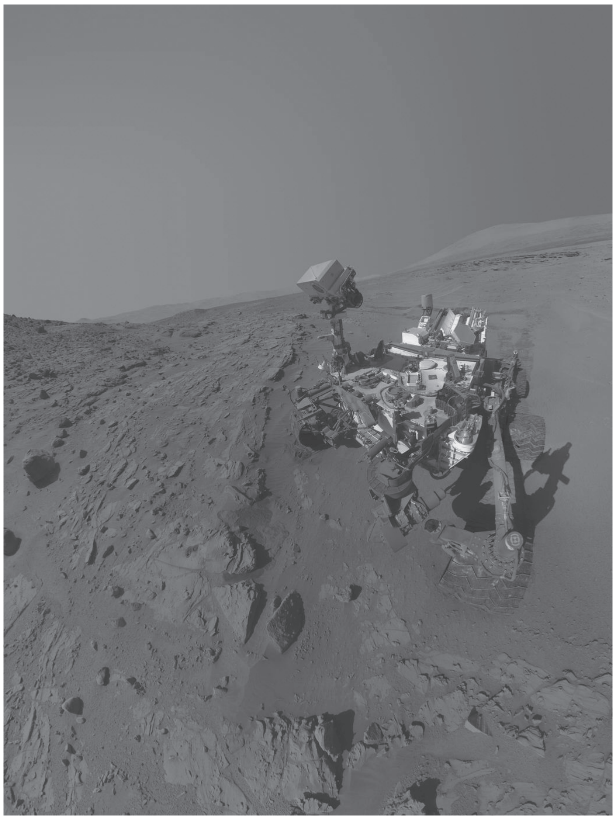

Figure 8.2
Nine years of persistent creativity and innovation enabled Curiosity, the robot, to travel 352 million miles in eight months so it could work on Mars.
(JPL-Caltech/MSSS/NASA)

The process summarized in the preceding seven steps was appropriately called *Audacity*. Successfully dealing with the radio delay between Earth and Mars meant the engineers and scientists knew they could not control the system in real time. Therefore, they had to exercise control autonomously, and they did so, assisted by five hundred thousand lines of computer code.

8.2.2 Lessons Learned

Landing the Curiosity rover certainly illustrates the creative/innovative power of persistence. It also demonstrates collaboration, as captured by mechanical engineer Steltzner, who led the effort and said, “That is one of the beautiful things about engineering. It is a collaborative art” (Ouellette 2013). Returning to persistence, recall President Coolidge’s “persistence and determination alone are omnipotent” comment, quoted in Section 6.8. We engineers can confidently be persistent partly because our education, experience, and observations enable us to understand fundamental physical, chemical, and biological principles and use them to do what needs to be done.

8.3 AGRICULTURAL ENGINEERING: PRECISION AGRICULTURE

Creativity and innovation are a common thread in the almost 250-year history of US agriculture, and engineers have played a major role. The following are a few examples of many and varied technical and nontechnical agriculture accomplishments (Taylor and Whelan 2014; USDA 2014):

- Invention of the cotton gin by Eli Whitney in 1793. This machine revolutionized cotton production by speeding up the process of removing seeds from cotton fiber. The word *gin* was derived from *engine*.
- Passage of the federal Morrill Land Grant College Act in 1862, which gave added impetus to formal agricultural education by granting land to states for establishing colleges that would teach agriculture and what was referred to as the *mechanic arts* (and now would be primarily engineering).
- Work by George Washington Carver at Tuskegee Institute from 1900 to 1910 to develop ways of diversifying southern agriculture by finding new uses for peanuts, sweet potatoes, and soybeans.
- Development of precision agriculture, beginning in the 1990s, with the first substantial workshop held in Minneapolis in 1992.

One indication of US agriculture’s success is that today’s farm population, which is about 1 percent of the US population, produces ample food for the nation and beyond (Alston et al. 2010). Let’s examine precision agriculture, one of this discipline’s innovative achievements.

8.3.1 Elements of Precision Agriculture

Precision agriculture may be defined as “a management system that is information and technology based, is site specific, and uses one or more of the following sources of data: soils, crops, nutrients, pests, moisture, or yield, for optimum profitability, sustainability, and protection of the environment” (McLoud, Gronwald, and Kuykendall 2007). From a farmer’s perspective, the building blocks for successful application of precision agriculture are as follows (Downey, Giles, and Slaughter 2004; McLoud, Gronwald, and Kuykendall 2007; Taylor and Whelan 2014):

1. **Data-collection process:** Data needs include, but are not limited to, soil type, temperature, moisture, nutrients, and organic matter; crop biomass; weed type

and location; crop yield; and land elevation. Examples of data sources include soil maps; topographic maps; soil sampling; ground-based platforms; and satellite, aerial, and drone imaging. All data collection must include temporal and spatial recording, with the latter usually being performed with GPS to facilitate later analysis and decision making.

2. **Data-management system:** Given the voluminous amount of necessary data, a farmer must have a system for organizing and processing data so that it's available for making decisions. Commercial and public domain software is available to manage data, including producing maps and other images that present inter- and intrafield spatial and temporal changes in crops and conditions that affect them.
3. **Analysis and decision-making process:** Data are used to recognize and solve problems and meet goals. Because analysis and decision making are complex and require significant hands-on time, consultants are often used to set up and manage the process.
4. **Specialized implementation equipment:** The purpose of this high-tech building block is twofold: (1) spatially apply crop inputs, such as seeds, fertilizers, herbicides, and pesticides at variable rates determined by current and expected site-specific field conditions; (2) measure crop yields spatially and temporally in order to assess results. Examples of specialized equipment include GPS guidance systems, auto-steer tractors, yield monitors, electrical conductivity and moisture-measuring devices, weed imagers, variable-rate applicators (Figure 8.3), variable center pivot irrigators, biomass sensors, and yield monitors. Considering the range of technologies used, precision agriculture nicely demonstrates Borrowing Brilliance, the whole-brain tool described in Section 4.3.
5. **Evaluation and improvement:** Using the extensive and growing data base, the precision agriculture process is assessed, and changes are identified and scheduled.

The prime benefit of precision agriculture is potential cost reduction through more effective and efficient use of resources, with a resulting improved economic return for farmers. It also reduces the farmer's risk, consistent with the idea that knowledge used is power. Precision agriculture can provide improved data recording and retrieval for food safety and environmental protection purposes. Soil and

Figure 8.3
Light-reflectance sensors on the front of this applicator measure nitrogen deficiency so that nitrogen can be automatically applied at the optimum rate.
(Newell Kitchen/USDA)

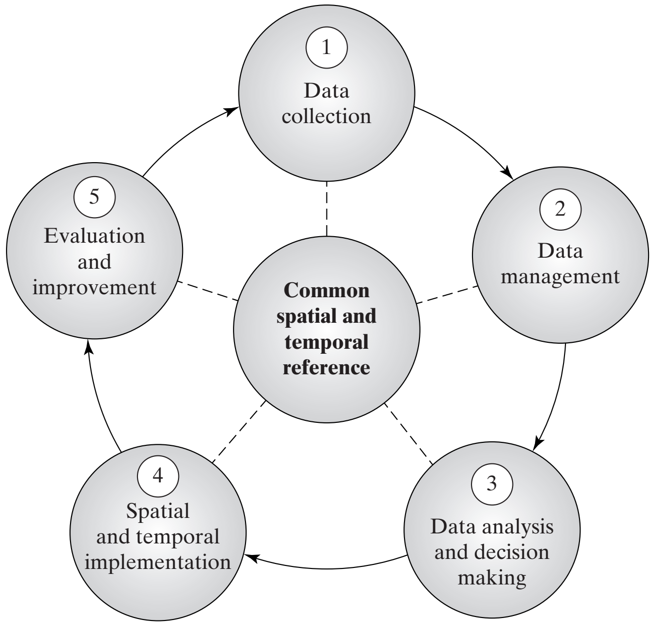

Figure 8.4
Five essentially simultaneous steps, all sharing a common spatial and temporal reference, define precision agriculture.
Source: Adapted from Taylor and Whelan 2014.

water quality benefits may occur because of reduced or more targeted application of nutrients, pesticides, herbicides, and irrigation (McLoud, Gronwald, and Kuykendall 2007, Taylor and Whelan 2014).

8.3.2 The Process: A Continuous Improvement Cycle

Using the building blocks just discussed, the precision agriculture process is illustrated in Figure 8.4. In its simplest form, the process is viewed as consisting of the following five steps: data collection, data management, data analysis and decision making, spatial and temporal implementation, and evaluation and improvement, all conducted with respect to a common spatial and temporal reference. In actuality, although one step may be emphasized at any given time, all steps essentially occur simultaneously in a dynamic fashion. Given the wealth of spatial and temporal data, the precision agriculture process enables classic continuous improvement.

8.3.3 Lessons Learned

As an outsider looking in at the agricultural engineering discipline, I marvel at how so few (the agricultural community enabled by that engineering discipline) can do so much in that only 1 percent of the US population provides food for the entire US population and beyond. The discipline's history of continued efforts to be more effective and efficient is admirable and offers a continuous improvement lesson. Another lesson learned, as exemplified by precision agriculture's adoption of an array of technologies, such as drones, satellites, GPS, and robotics, is that any engineering discipline can borrow brilliance from various engineering and other disciplines.

8.4 BIOMEDICAL (ELECTRICAL AND MECHANICAL) ENGINEERING: BIONICS

Five hundred or more people in the United States have one or more limbs surgically amputated each day. These limbs are lost for a variety of reasons, such as diabetes, heart disease, cancer, accidents, war, and various illnesses. Limb loss is expected to increase in an aging (and maybe less health-conscious) society. Prostheses—that is, artificial devices that augment or replace a missing or impaired body part—are highly valued by most amputees (Platt 2012). In addition to loss of limbs, some individuals suffer partial or complete loss of hearing and vision.

HISTORIC NOTE: PROSTHETICS GO WAY BACK

As one indication of human creativity and innovation, prosthetic devices first appeared three thousand years ago. For example, in 2000, archeologists working in Cairo, Egypt, discovered a very real-looking prosthetic toe fashioned from wood and leather and attached to the foot of the three-thousand-year-old mummified remains of a wealthy Egyptian. In the Middle Ages, some armored knights were equipped with prosthetic limbs crafted by armorers, probably more for appearance than function. And of course, pirates had wooden peg legs and artificial hands with metal hooks. In the fifteenth and sixteenth centuries, European doctors added hinges, locking joints, and improved means of attaching prostheses.

In more recent times, newer, lighter, and stronger materials, such as plastics and carbon-fiber composites, have been used. The socket, the portion of a prosthesis that interfaces with the limb's stump, has been improved, as has the joint mechanism, all of which are suggested by Figure 8.5.

Figure 8.5
Prosthetic devices have advanced through use of lighter materials, better interfaces, and improved joint mechanisms.
(Belahoche/Fotolia)

Physical therapy accompanies a new prosthesis so that the device performs well in everyday activities. Functional devices also have appeared—that is, those that can be controlled mechanically by cables connected to other parts of the body, such as a prosthetic arm connected to a healthy shoulder. Motor-powered prostheses are controlled by the patient using switches or buttons. The most recent, exciting, and creative/innovative development that takes prosthetics up to the next level, as discussed next, is bionics (Clements 2014; Herr 2014).

8.4.1 Bionics: Taking Prosthetics to the Next Level

Within the medical field, *bionics* means the study and use of mechanical and electronic systems that function like living organisms (or part of them), with the systems being controlled by the organism. This approach is potentially powerful in prosthetics because even when flesh and bone are damaged or missing, nerves and related brain parts continue to function. Therefore, in bionics, a person's damaged or missing body parts are replaced with devices connected to the individual's nervous system, and the devices respond to commands from the person's brain.

The prosthetic device, a machine that may be called a neural prosthesis or robotic prosthesis, is linked to the brain (Fischman 2010; Herr 2014). As you can imagine, many specialists contribute to advancing bionics, including medical doctors, neuroscientists, physical therapists, and, certainly not least, biomedical engineers. For our purposes, *biomedical engineers* are primarily electrical and mechanical engineers.

Linking the Brain and the Prosthesis

From a system perspective, what are the scientific principles and engineering challenges behind neural prostheses? How does bionics work? The challenge in linking the brain and a prosthesis is that although nerves activated by the brain conduct electricity, those nerves cannot be directly spliced and wired to the prosthesis. Even if connections could be made, the connections between nerves and wires would invite infections. Furthermore, those nerve signals are very weak, and regardless of how the brain–prosthesis connection is made, those signals have to be detected so they can be used.

The answer was found to be in muscles: "When muscles contract, they give off an electrical burst strong enough to be detected by an electrode placed on the skin." As suggested by Figure 8.6, biomedical engineer and physician Kuiken "developed a technique to reroute severed nerves from their old, damaged spots to other muscles that could give their muscles the proper boost" (Fischman 2010). Those nerves start in the brain and extend into what remains of the lost limb.

After the intricate operation, the patient eventually begins to feel parts of the *phantom* (no longer there) limb, the presence and function of which were mapped into his or her brain. Then, the patient is fitted with the bionic limb, which, as also shown in Figure 8.6, has electrodes embedded in the interface (the cup that fits around the stump), with the idea that the electrodes will sense the muscle signals.

The prosthesis contains one or more electric motors and a microprocessor, and is intended to mimic the action of its natural counterpart. Working with a technical

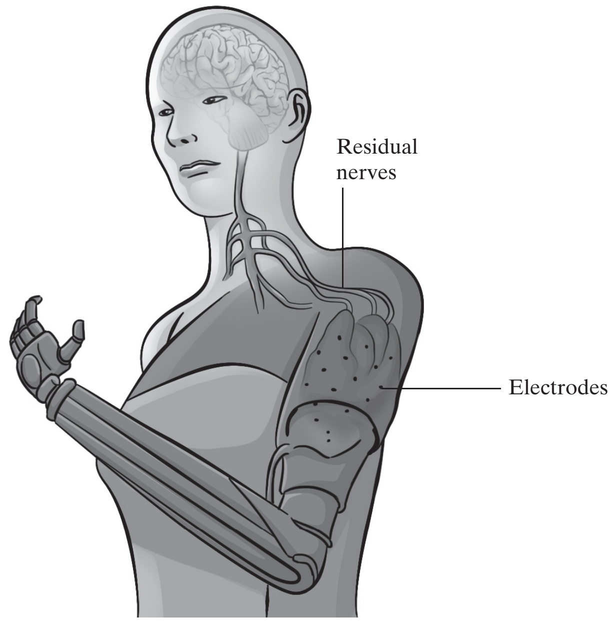

Figure 8.6
The brain–prosthesis connection begins with an operation to connect residual nerves to muscles, which in turn transmit signals to electrodes in the prosthesis.
Source: Adapted from Fischman 2010.

expert, the patient learns to convert those signals to desired movements of the artificial limb. The microprocessor in the prosthesis is gradually programmed to look for the correct signals from the brain via the muscles and activate the appropriate motors. From then on, conscious and subconscious thinking activate the prosthesis (Fischman 2010).

More Innovation

As we might expect within such a creative/innovative environment, other improvements are underway. For example, biomedical engineers are adding more motors to the prostheses for more functions and developing pressure-sensitive figure pads to aid patients. Other biomedical engineers are using bionics to give new life to a limb that although it is still basically intact, does not function because of nerve damage between the brain and the limb (Fischman 2010). Exoskeleton neuroprostheses—that is, devices that wrap around limbs—are being developed for use by paraplegics and people with muscular disabilities and to generally enhance people's physical capabilities (Herr 2014).

Retinal implant neuroprostheses help to restore vision. They consist of a retinal implant, a camera to capture light, and a processor to convert incoming video signals into electrical signals for transmission to the cortex. A similar neuroprosthesis, called a cochlear implant and named after the coil in the inner ear, is available to restore hearing (Gibb 2012).

These vision and hearing neuroprostheses remind us, as nicely stated by scientist Gibb, that "in reality, hearing, vision, and other sensory impressions occur inside the brain, created from variations in the chemicals, light, air, and physical forces we're exposed to." Our ears don't hear, and our eyes don't see: They are visible sensory receptors that convert sound waves and light to electrical signals that are sent to the brain for processing, enabling us to hear and see. Replacing or repairing the natural sensor function continues to hold great promise for collaboration between engineers and medical professionals.

Figure 8.7
Kitts' bionic prosthesis, which is controlled with her thoughts, enables her to perform just about any activity with the five-year-old children in her day-care center.
(Clay Owen/Knoxville News Sentinel)

8.4.2 Bionics Examples

Amanda Kitts, a Knoxville, Tennessee, day-care center operator, lost her left arm from just above the elbow in a 2006 car accident. She benefits from the creative/innovative efforts to restore the links between the brain and the mind (see Figure 8.7).

Her neuroprosthesis consists of three motors, a metal frame, an electronics network, and a white plastic cup that fits over her biceps. After the operation to reroute nerves to muscles, the nerves grew deeper into the muscles. At four months, Kitts began to feel different parts of her phantom hand. Working with a research engineer, she gradually learned how to use her thoughts to control her prosthesis; it wasn't easy. When asked how it works, she said, "I don't really think about it. I just move it" (Fischman 2010).

Thirty years ago, mechanical engineer and biophysicist Hugh Herr lost both legs in a mountain-climbing accident. Severe frostbite required the amputation of both his limbs below the knee. Now he heads the biomechatronics group in the MIT Media Lab, where he led the development of two robotic prostheses that let him not only walk, but also run.

Ballroom dancer Adrianne Haslet-Davis lost her left leg as a result of the 2013 Boston Marathon terrorist bombing. Under the creative/innovative leadership of Herr, and with the participation of many experts, a robotic prosthesis was designed and built for Haslet-Davis: Its intended purpose went way beyond walking. About two hundred days after losing her left leg, Haslet-Davis and a partner danced beautifully during a TED (Technology, Entertainment, and Design) Talk (Herr 2014).

PERSONAL: TRY TED

TED Talks, although formally addressing technology, entertainment, and design, go beyond such topics into science, business, the arts, and global issues. Each audiovisual presentation lasts eighteen minutes or less, is well prepared, and is professionally presented.

Whenever you view a TED Talk, you will simultaneously learn about an interesting topic of your choice and receive a lesson in effective speaking. TED Talks are closely aligned with this book because both value innovation. If you want to learn more, go to the following website, launched in 2007, where you can view any of the talks at no cost: www.TED.com.

8.4.3 Lessons Learned

What immediately comes to my mind, no pun intended, as a result of this bionics introduction is that if creative/innovative minds conceive something, they can probably make it happen. With bionics, creative/innovative individuals conceived using minds to control prostheses and made it happen with the potential to vastly improve the quality of life for many. As with other creations and innovations described in this chapter, the bionics story is one of collaboration among many specialties, with two of the leading ones being electrical and mechanical engineering. You could be one of those collaborators and help improve the quality of life for many people around the globe.

8.5 CHEMICAL ENGINEERING: DESALINATION

Consider the world's supply of water. Only 2.5 percent is fresh water; two-thirds of that is frozen in glaciers and ice caps. A growing global population increasingly wants to draw on the 97.5 percent of Earth's water—salt water—in the oceans (IDA 2014). However, that water will kill humans. When the body senses salt in its systems, cells expel water molecules through the process of osmosis to dilute the salt. This depletes the cells of moisture, which impedes kidney function and damages the brain.

Recall the line "water, water, everywhere, nor any drop to drink" in English poet Coleridge's "The Rime of the Ancient Mariner." Many of Earth's inhabitants are surrounded by water, whether seawater or otherwise undrinkable water, but don't have "any drop to drink" (Dove 2014). The chemical engineering profession is taking the lead in meeting this challenge by creatively and innovatively developing and continuing to improve desalination.

8.5.1 Introduction to Desalination

Desalination is the process by which dissolved salts are removed from seawater to produce potable water for domestic and municipal purposes. Desalination occurs naturally in nature in the form of the hydrologic cycle. Water evaporates from the oceans and from lakes and streams via the sun's energy, leaving dissolved minerals and other substances behind. The water vapor condenses and forms clouds that produce rain, which restores freshwater sources, and the cycle continues. Engineered desalination seeks to augment this process in site-specific locations to meet human needs (IDA 2014; USGS 2014).

The US Geological Survey defines *freshwater* as having a dissolved salt concentration by weight of one thousand parts per million (ppm) or less. In contrast, the oceans contain about 35,000 ppm (USGS 2014). Therefore, the engineering challenge of desalination is to economically remove at least 97 percent of the salt in an environmentally sensitive manner.

HISTORIC NOTE: CENTURIES OF DESALINATION

The need for freshwater, coupled with human creativity and innovation, led humans through two millennia of desalination. According to the International Desalination Association (2014), Aristotle wrote about seawater distillation in 320 BC, the Romans distilled seawater using condensation on fleece, the Greeks distilled with sponges, and seafaring explorers desalinated seawater during long voyages. Until the end of World War II, thermal evaporation followed by condensation was the most common form of distillation. In the postwar years, scientists and engineers began to investigate other desalination approaches, such as osmotic processes developed in the 1950s and described in this section.

As of 2009, about fourteen thousand desalination plants were operating in over 120 countries. The freshwater they were producing accounted for less than 1 percent of the world's freshwater consumption. Approximately 70 percent of the globe's desalination capacity is in the Middle East; California and Florida are the principal users of desalination in the United States. The process's cost has restrained its global use. Today, about 90 percent of desalination plants use either the reverse osmosis or multiflash process, with the former being the most common because it is usually less costly (Dove 2014; USGS 2014).

8.5.2 Osmosis

As is the case in essentially all creative/innovative efforts within engineering, the design and operation of desalination plants around the globe draws on fundamentals, those concepts and theories you begin to study as a first-year engineering student. These basics, most of which are taught and learned throughout your undergraduate engineering program, include osmosis. Let's discuss osmosis principles; depending on where you are as a student or practitioner, this will be either an introduction to the topic or a review of it.

Osmosis is the spontaneous net passage or diffusion of molecules of a solvent, such as water, through a semipermeable membrane from a place of lower solute concentration to a place of higher concentration, while blocking passage of the solutes, until the solute concentration is equal on both sides. Consider the left side of Figure 8.8, which shows a container of water at time zero with a low concentration of salt on the left side of the semipermeable membrane and high concentration of salt on the right side.

Osmosis begins as soon as the container and its contents are prepared. The system will seek equilibrium—that is, equal salt concentration on both sides of the membrane—and will achieve that state due to water moving from the left side to the right side, as shown on the right side of Figure 8.8. Water and not salt moves through the membrane because water is composed of much smaller molecules than salt. The driving force—the net movement to the left of water molecules through the membrane—is called *osmotic pressure* and is indicated by the final difference in water levels (Dove 2014; Kershner 2014).

Although our primary interest is understanding osmosis so that we can get on with further exploration of desalination, consider the vital and broad application of osmosis within the human body, including the brain. As noted in Section 8.5.1,

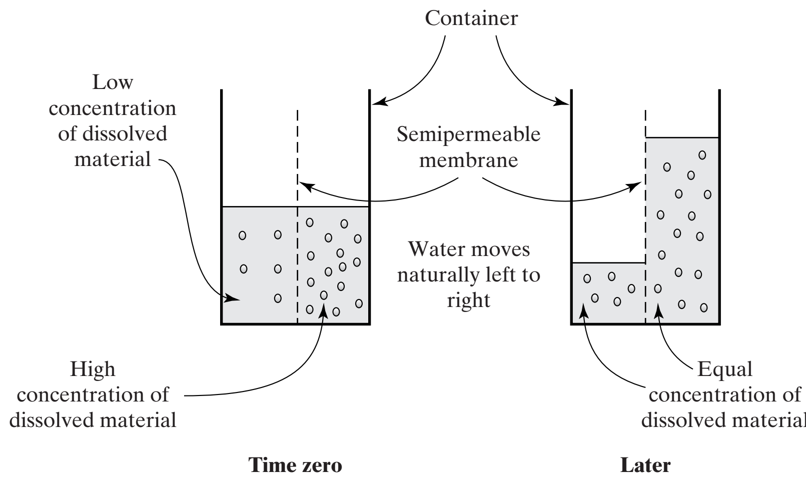

Figure 8.8
Osmosis is the natural process by which a solvent-solute system partitioned by a semipermeable membrane seeks equal solute concentration by, in this case, having water move from left to right, driven by osmotic pressure.

when the body senses salt in its systems, its cells expel water molecules through the cell membranes to dilute the salt. If that osmotic action continues unabated, it threatens the kidneys and the brain. More generally, osmosis is used throughout the body to regulate the flow of certain substances, such as water and gases, into and out of cells (Baggaley 2001).

Returning to desalination, understanding it requires understanding osmosis, but that is not enough. Desalination uses osmosis but reverses it, as described in the next section.

8.5.3 Reverse Osmosis

Reverse osmosis capitalizes on one of the natural or "forward" osmosis features. More specifically, if we are considering two saltwater solutions of different concentrations separated by a semipermeable membrane, water, but not salt, moves through the membrane because water is composed of much smaller molecules than salt. This fact is the key to reverse osmosis.

For an illustration of reverse osmosis, assume saltwater is placed on one side of a semipermeable membrane and pure water on the other side, as shown in Figure 8.9. Then, a large pressure, greater than the opposing left-to-right osmotic pressure, is applied to the liquid in the left side of the container. Freshwater flows

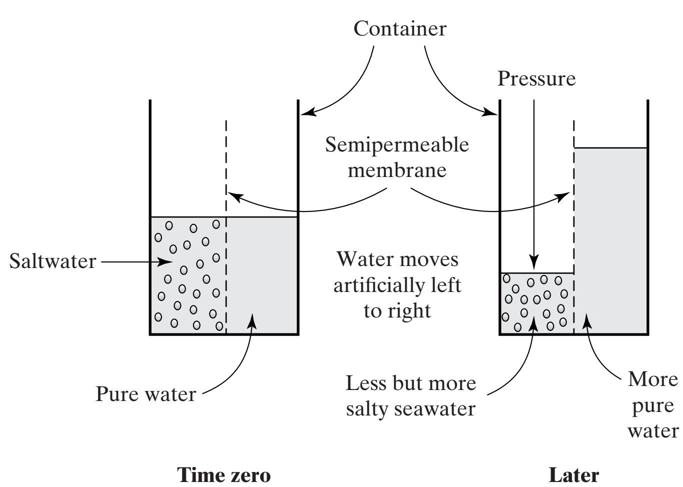

Figure 8.9
Reverse osmosis is the engineered process by which a solvent-solute system, partitioned by a semipermeable membrane, uses externally imposed pressure to force water from a high-salt concentration supply to create an acceptably low-salt supply.

from left to right through the membrane, adding to the freshwater supply on the right side of the membrane (Dove 2014; Kershner 2014).

Reverse osmosis became operational in the 1960s as a result of the work of chemical engineers Loeb and Sourirajan. They developed membranes from cellulose acetate, a polymer used in photographic film, that markedly improved the water diffusion rate. In 1965, that key innovation led to the world's first, although small, reverse osmosis desalination plant, which went into operation in Coalinga, California (Economist 2008). Pores used in today's reverse osmosis membranes are one hundred thousandth the diameter of a human hair (ACS 2014).

8.5.4 An Example: Tampa

A brief review of the Tampa Bay Seawater Desalination facility in Florida introduces us to the water supply achievements of chemical engineers and others (Tampa Bay Water 2014). This reverse osmosis facility can provide twenty-five million gallons per day (mgd) of drinking water, which meets about 10 percent of the region's needs.

The plant's principal sequential processes, when producing 25 mgd of drinking water, may be summarized as follows:

- Withdraw 44 mgd from the cooling water being discharged from Tampa Electric's Big Bend Power Station, which, along with the reverse osmosis facility, is on Tampa Bay.
- Filter out debris (e.g., shells and wood) greater than one-quarter inch in size using screens.
- Settle out particles in sedimentation tanks.
- Remove smaller particles using sand filters.
- Capture microscopic particles in diatomaceous earth filters.
- Remove remaining particles by pumping the water through cartridge filters.
- Separate the water from the salt by pumping the seawater through reverse osmosis membranes, leaving 19 mgd twice-as-salty seawater to be mixed with the discharge from the power station and returned to Tampa Bay.
- Post-treat the remaining 25 mgd of drinking water to stabilize it.
- Pump 25 mgd of drinking water to a regional facility, blend it with treated drinking water from other sources, and deliver the water to users.

8.5.5 Building on Positives to Meet Challenges

Clearly, the principal benefit of desalinization, regardless of the process used, is the ability to draw on the vast ocean source of water. We can get at some of that 97.5 percent of Earth's water that is undrinkable and provide a basic human necessity.

Challenges of the reverse osmosis approach to desalination include high construction and operation and maintenance costs relative to more traditional water supply treatment methods. These costs reflect in part having to engineer environmentally sound ways to deal with the leftover salt—that is, the brine that has twice the salt concentration of seawater. Higher maintenance costs occur in part because membranes must be protected by pretreatment unit processes and cleaned frequently and because of energy usage. Distillation plant inflows and outflows also can adversely affect marine life. (IDA 2014; Kershner 2014).

These negatives pose creativity/innovation challenges for chemical engineers and other engineering and scientific professionals. These challenges will be met, as suggested by the following recent and current research and development efforts:

- Use of solar and wind energy to power the desalination process (Harrington 2013; IDA 2014)

- Biomimetic membranes (see Section 7.2) inspired by those in human kidneys and red blood cells, which exhibit high water permeability and favorable solute-trapping selectivity (IDA 2014)
- Lessening the impact on marine life during a distillation plant's intake and outfall processes (IDA 2014)
- Using fully submerged buoys to extract wave energy and use it to pump water to onshore hydroelectric turbines that will send water through reverse osmosis membranes in a desalinization plant (Harrington 2013)

8.5.6 Lessons Learned

As the engineering profession continues to create and innovate, as illustrated by reverse osmosis desalination, valuable advancements draw on science and engineering science topics taught and learned early in the engineer's formal education. As engineering students, when we are introduced to fundamentals such as Newton's laws of motion, conservation of energy, or osmosis, we may question the value of what appear to be esoteric, theoretical principles. However, as illustrated by the preceding desalination discussion and by the other creative/innovative developments described in this chapter, those basics are the foundation of creativity and innovation; they define what is possible. It is up to us to make it happen—and maybe, for some of us, to discover additional fundamentals.

Another lesson learned from desalination is the idea that when engineers resolve a societal or environmental challenge, they inevitably produce additional related challenges. The amazing global benefits of desalination illustrate this phenomenon. As suggested by the previous section, engineers will creatively and innovatively resolve the new issues.

8.6 TRANSPORTATION ENGINEERING: TEMPORARY USE OF A BRIDGE

In 2009, civil engineers faced a challenge involving two bridges over the Capilano River near Vancouver, British Columbia. As shown in Figure 8.10, the river is crossed

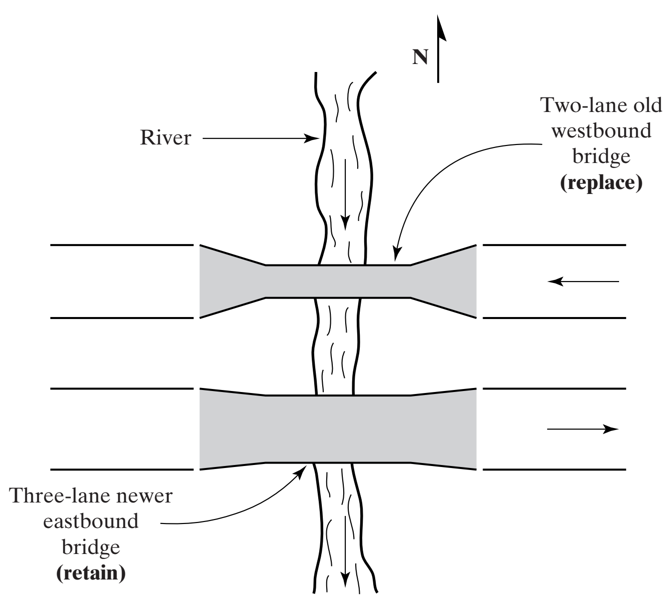

Figure 8.10
The two-lane bridge needs to be replaced with a three-lane bridge.

Figure 8.11
The old two-lane bridge consists of a two-span steel truss structure.
(British Columbia Ministry of Transportation and Infrastructure)

by two bridges owned by the British Columbia Ministry of Transportation and Infrastructure. One was a relatively new, three-lane, eastbound bridge served by a three-lane highway, and the other, as shown in Figure 8.11, was an old, two-lane, westbound bridge constructed in 1929 to serve two lanes of opposite traffic but now serving the volume of three lanes of one-way traffic. The two-lane bridge needed to be replaced by a three-lane structure consistent with the three-lane highway it serves (Johnson, Queen, and Sandhu 2012).

8.6.1 Options and the Solution

Because of high traffic demands and lack of practical alternative routes, a temporary detour bridge would be required for westbound vehicles during construction. The temporary detour bridge would have to be temporarily constructed as close to the old bridge as possible while allowing space to construct the wider westbound three-lane bridge. This initial concept is illustrated in Figure 8.12.

Review of that conventional approach led to the development of an innovative second option (Figure 8.13). The old bridge would be moved to the north—slid onto a newly constructed temporary central pier and two temporary abutments—to serve as a temporary detour bridge. Then, the new westbound bridge would be constructed and put into service and the old bridge removed. This bridge-sliding option was selected.

Moving the old bridge to its new temporary location caused minimal traffic interference. Highway traffic was disrupted for only seventeen hours (from 6:00 p.m. on Saturday, June 19, 2010, to 10:30 a.m. on Sunday) while the old bridge was pushed to its temporary new location. The sliding operation used the following four steps:

1. Lift the bridge with vertical hydraulic jacks at the west and east abutments and the center pier.

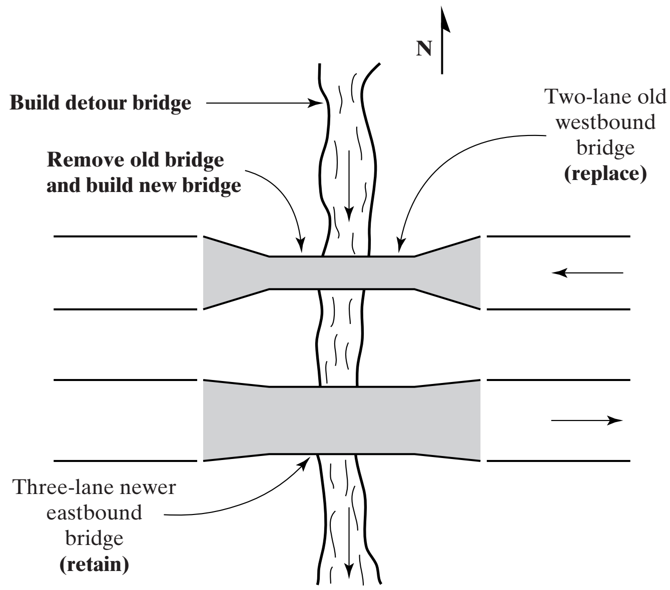

Figure 8.12
The first option considered was to build a temporary westbound detour bridge, remove the old westbound bridge, construct the new westbound bridge, and remove the temporary bridge.

2. Attach sliding shoes to the bottom of the bridge at the intended contact points and install and grease the underlying steel sliding tracks.
3. Lower the bridge so that the sliding shoes rest on the tracks.
4. Use horizontal jacks to slide the bridge to its new location on the just-constructed and temporary central pier and two temporary abutments.

Looking from west to east, Figure 8.14 shows the old bridge in its new temporary location serving as a detour during construction of the new westbound, three-lane bridge. The completed project, with the new westbound bridge in place and the old bridge removed, is presented in Figure 8.15.

Besides the benefit of minimal traffic interference, the owner saved about \$500,000 because moving the old bridge to a temporary new location was less costly

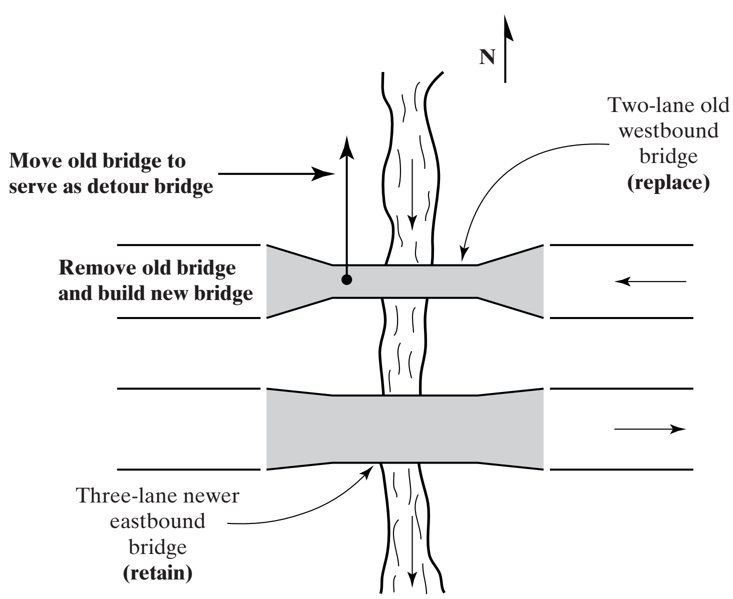

Figure 8.13
The first option led to the innovative second idea, in which the old westbound bridge would be moved to the north to serve as a temporary westbound detour while the new westbound bridge was constructed.

Figure 8.14
Contractors slid the old bridge to its temporary new location to carry westbound traffic so that the new wider westbound bridge could be constructed.
(British Columbia Ministry of Transportation and Infrastructure)

than constructing a new temporary bridge. Furthermore, the selected option had minimal impact on the local salmon runs in the Capilano River. How might this innovative concept apply elsewhere? How might we slide, lift, lower, turn, tip over, or turn around something to serve a temporary function during construction?

Jones (2012) describes a 2012 Nevada Department of Transportation project referred to as *accelerated bridge construction* (ABC). In this case, bridge slides

Figure 8.15
The complete project with the new westbound bridge in place and the old bridge removed.
(British Columbia Ministry of Transportation and Infrastructure)

somewhat like the one described previously were used for both the northbound and southbound lanes of Interstate 15. The two new bridges were constructed next to the existing bridges; as soon as the existing bridges were removed, the new bridges were slid into place with minimal traffic disruption.

ABC and other sliding approaches are transitioning from being innovative to becoming common, as is often the ultimate result of innovation and how the engineering field moves forward. As a student or practitioner, you can help the profession advance and provide even better service to society by being open to new ideas and creative and innovative approaches in your studies and work.

8.6.2 Lessons Learned

First ideas are often not the best ideas. They tend to reflect the Einstellung Effect discussed in Section 3.4. That is, as in the case described here, when faced with a well-defined challenge, we first tend to recall a past similar challenge and how it was resolved. Although that line of thinking is prudent and may ultimately be fruitful, we should parallel it with a creative/innovative process using one or more of the tools described in this text. Allow for major divergent thinking to generate many options; then, and only then, move to convergent thinking to sort them out.

Another lesson learned from this case study is the value of collaboration during planning and design between engineers and contractors. Although each ultimately has specific project responsibilities, sharing knowledge early on enhances the probability that creative/innovative ideas will be discovered and successfully implemented.

8.7 WATER RESOURCES ENGINEERING: MULTIPURPOSE STORM WATER FACILITY

For this example, let's consider the design, financing, and construction of a multipurpose urban storm water management facility (American Society of Civil Engineers and Water Environment Federation 1992; Donohue and Associates 1984). The project and related 2.96 square mile watershed were within and near the city of Valparaiso, Indiana, as shown in Figure 8.16. At the time of the project (the 1980s), Valparaiso had a population of twenty-two thousand. Serious flooding had occurred in recent years, as shown by the flood-prone areas in Figure 8.16, even though the watershed included two storm water detention facilities.

Therefore, the city retained an engineering firm to prepare a comprehensive flood control plan for the watershed and ultimately to design the major recommended facility. This provided an opportunity for the consultant, the client, and others to explore some innovative technical, financial, and other approaches that could benefit the community.

8.7.1 Engineering Guidelines Set the Stage

The engineering firm prepared engineering guidelines, which were supported by the client, to set the stage for taking a comprehensive, innovative approach to solving the flooding caused by medium to large storms. The guidelines are summarized as follows:

- Size and configure storm water storage facilities to store or convey runoff from the one hundred-year recurrence interval, six-hour rainfall occurring under future land use conditions. The six-hour duration was selected using watershed-modeling sensitivity analyses.

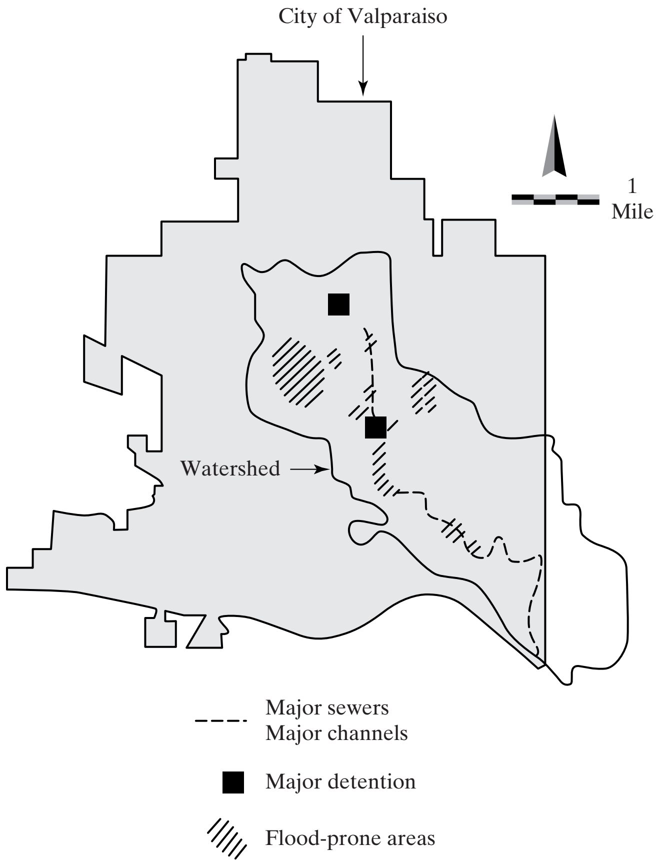

Figure 8.16
Serious flooding occurred within one of the watersheds lying wholly or partly within Valparaiso, Indiana.

Source: Adapted from American Society of Civil Engineers and Water Environment Federation 1992.

- Resolve flood problems as close as possible to their origin and avoid transferring problems from one location within or outside of the watershed to another.
- Address extensive and serious surface flooding problems with an eye toward beginning to resolve sanitary and combined sewer backup problems.
- Favor gravity inflow and outflow for detention/retention facilities.
- Give preference to a few large, publicly owned and maintained detention/retention facilities and try to avoid many small, privately owned facilities.
- In addition to flood control, consider potential recreational and aesthetic aspects of all detention/retention facilities.

The details will vary, but preparing or assembling planning, design, or other guidelines somewhat like the preceding example is advisable on the front end of or early on into any potentially complex engineering project. Sometimes, such guidelines are included in the engineer and client contract or are prescribed by state, federal, or other entities. However, do what you can to define the depth and breadth of the subsequent engineering as early as possible, especially if you want to set the stage for possibly exploring creative/innovative options. Get everyone on the same page in terms of expectations and craft the guidelines so as to encourage creativity and innovation in addition to conventional approaches. Don't presume the solution.

8.7.2 Analysis and Recommendations

Diagnosis of the watershed hydrologic–hydraulic system using simulation revealed that the existing detention facilities were undersized and that major channels and

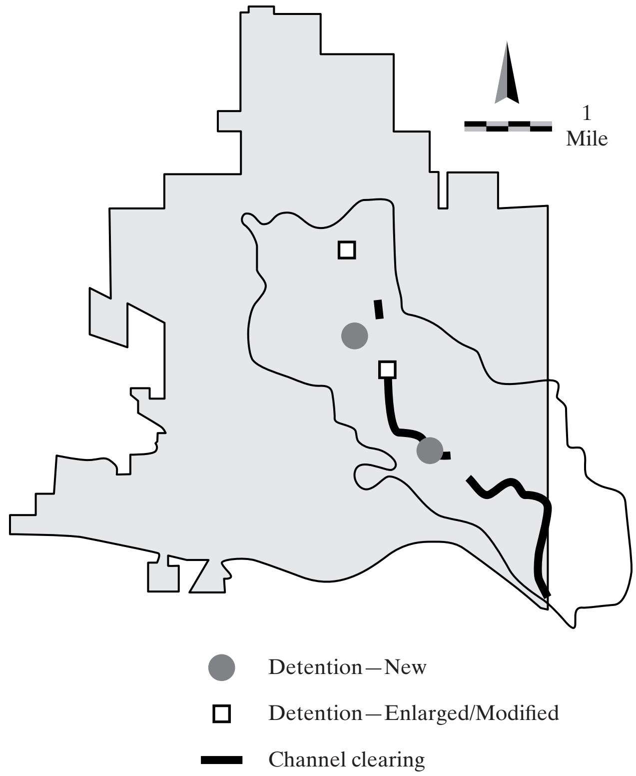

Figure 8.17
The engineering firm recommended new and modified detention facilities and channel clearing.
Source: Adapted from American Society of Civil Engineers and Water Environment Federation 1992.

conduits through built-up areas had insufficient conveyance capacity. Future urbanization would worsen flooding in scattered locations throughout the watershed. Various alternative structural flood control facilities and nonstructural measures were evaluated. The recommended major improvements, shown in Figure 8.17, include construction of two new detention facilities (one of which will soon be discussed in detail), modification of two existing detention facilities, and extensive channel cleaning and maintenance.

The firm also recommended that the city prepare a program for operation and maintenance of sewers and channels; that owners or renters of residential or commercial property purchase flood insurance; that the city review and upgrade its storm water management regulations; and that the city, perhaps in cooperation with the county, develop a storm water management plan for all watersheds in the Valparaiso area.

Since issuance of the plan, the recommended channel cleaning was completed, the two existing detention facilities enlarged as recommended, and the two recommended new detention facilities constructed. In order to illustrate some creative/innovative aspects of this project, let's focus on the northernmost and largest of the two recommended new detention facilities.

8.7.3 Design of the Major Detention Facility

Figure 8.18 shows the twenty-seven-acre site then available. Although it was in the city, it was owned by the county because it was the recent home of the annual county fair and other outdoor events. Also shown is the initial idea for a single-purpose, offline, rectangular detention facility that would occupy the eastern 41 percent of the site so that the city would not have to purchase all twenty-seven acres or so that the remainder

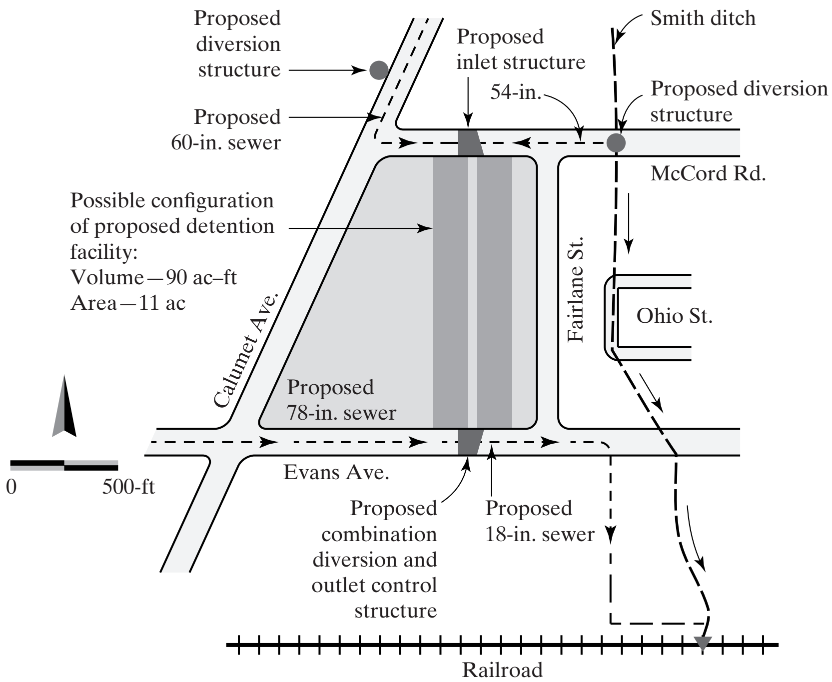

Figure 8.18
The initial idea was to construct a single-purpose storm water detention facility on the eastern eleven acres of the twenty-seven-acre site.
Source: Adapted from American Society of Civil Engineers and Water Environment Federation 1992.

of the available land could be used for other purposes. This is the point at which the engineering group, in keeping with What If (Section 4.12), asked, “What if we used a new point of view?” Instead of moving to the design step, the engineering team stepped back and asked what else was occurring in and near the city.

Coincident with the need to solve the flooding problems, the recreation needs of the city were receiving attention. The park and recreation board contracted preparation of a citywide park master plan. Because that recreation planning effort was carried out approximately parallel to the flood control planning effort, the flood control and park professionals began to collaborate on possible flood control and recreational use of the twenty-seven acres available.

Figure 8.19 presents the initial concept for a flood control/recreation development. The eastern approximately one-third of the site would be excavated to provide the necessary ninety acre-feet, one-hundred-year recurrence interval flood storage when needed, as well as supporting three soccer fields and two softball fields. An additional two softball fields and other athletic fields would occupy the remaining nonflood control portion of the available land, along with a restored building in the southwest corner that would serve as a large park shelter.

Further collaboration and the opportunity to remove an old concrete grandstand on the west center portion of the site resulted in the final site configuration shown in Figure 8.20. A set of terraces would cover the site, and the originally flat site would now have a total relief of thirteen feet, with the lowest area at the outlet in the southeast corner. The least used portions of the facility, such as one of the overflow soccer areas, would be on the lowest levels. In contrast, frequently used areas, such as lighted softball fields, would occupy the highest terraces.

A network of four- to eighteen-inch diameter perforated and corrugated polyethylene pipe would provide subsurface drainage of recreation areas. Recreation surfaces would have a surface slope of at least 1 percent to encourage rapid drainage after rainfall or flooding. Because of these design features, even the lower recreation

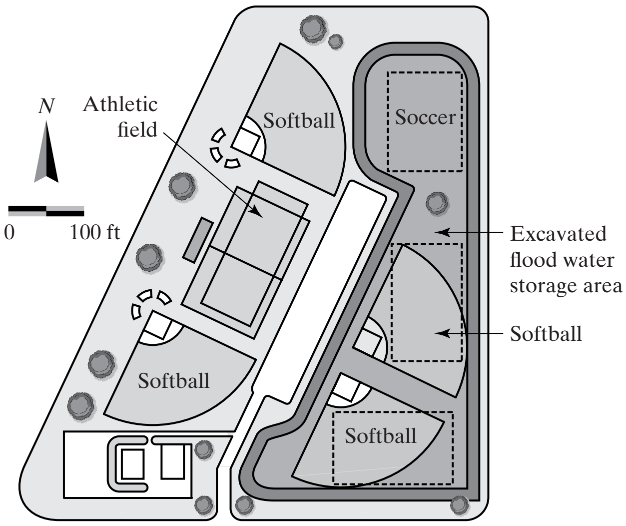

Figure 8.19
Collaboration of engineers and park planners led to this initial multipurpose concept.
Source: Adapted from American Society of Civil Engineers and Water Environment Federation 1992.

facilities on this site would probably be available for use more often than other single-purpose facilities scattered around the city. The final design provided numerous and varied active and passive recreation opportunities and included onsite provision for service and maintenance facilities and equipment. The value of the constructed project was about $2.4 million then, or about $5 million today.

8.7.4 Finance and Construction of the Facility

After completing the design, the project team turned to financing the multipurpose facility. Major public works projects like this are typically financed through sale of bonds. Again, the team applied the What If approach and, although a bond issue was used to finance much of the cost of the facility, other innovative means of finance were also used. The engineering and park and client group took the thirty-thousand-foot view and asked what else was going on in the Valparaiso area. This perspective led to several cost-saving finance innovations:

- In the summer of 1985, the city and its park and recreation department committed to proceed with the multipurpose project. After obtaining an appraisal

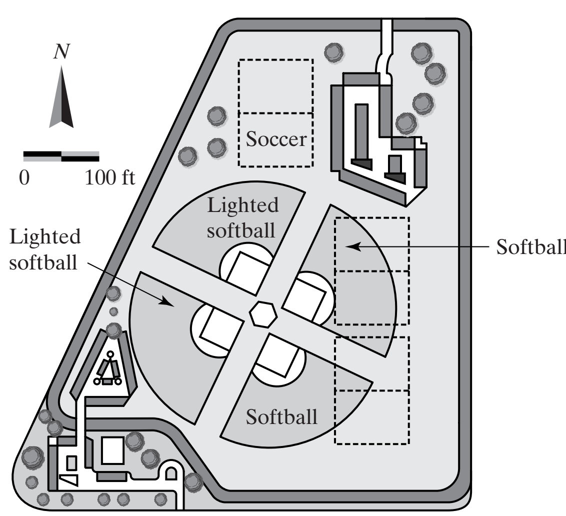

Figure 8.20
Further collaboration produced the final multipurpose design.
Source: Adapted from American Society of Civil Engineers and Water Environment Federation 1992.

for the twenty-seven-acre fairgrounds site, the city negotiated with the county for site acquisition. The city purchased the site in August 1985 for $300,000, which would be paid in six annual amounts of $50,000 at zero interest. The negotiations included the city agreeing to give the county first right of refusal on a city-owned parking lot close to the county courthouse.

- Negotiations then proceeded with the city and the Valparaiso community schools, with the result that the school system would give the city 11.3 acres of land elsewhere in the city, valued at $254,000. The Valparaiso community schools held this land to meet anticipated future education needs. In return for the land, the city agreed to provide certain recreation facilities at the new fairgrounds facility or elsewhere for use by the school system. This innovative exchange offset most of the cost incurred by the city in purchasing the fairgrounds because the city could sell the land acquired from the school system as a means of recovering the flood control/recreation facility land purchase price or other costs incurred in providing the additional recreation services. With some major financial matters resolved, construction began while innovative financing continued.
- Construction of a bypass highway in the vicinity of Valparaiso, which was underway when the construction began on the flood control/recreation facility, generated a strong demand for fill material. The fill areas were 1.6 miles or more away from the flood control/recreation site, suggesting that a long haul would cause high excavation costs. However, the city began to investigate the possibility of providing fill for the highway project because site excavation costs were a large part (about one-third) of the total cost of the project. The city advertised the availability of up to 210,000 cubic yards of material at its project site and received six bids, with the lowest being submitted by a contractor involved in the bypass highway project. That contractor won the contract and eventually removed 180,500 cubic yards from the site to the highway project for $1.02 per cubic yard ($184,100). Assuming that the original estimate of $4.20 per cubic yard for excavation in 1985 costs would have applied in absence of the tie-in to the highway project, the city saved $574,000 by moving innovatively and quickly, integrating its detention facility construction with the bypass highway construction.
- In exchange for a time extension, the contractor who was excavating and hauling material agreed to provide additional services at no cost to the city. These services included stripping and stockpiling topsoil at the site, rough grading, placing topsoil on the steeper side slopes, seeding and mulching those slopes, and demolishing and removing the previously mentioned concrete grandstand. These services amounted to an additional savings of at least $20,000 to the city.
- Before planning and design of the flood control/recreation project, and completely unrelated to it, the city, state, and federal government had been designing and preparing financing for improvements to a portion of the busy street bordering the west side of what now would be a multipurpose facility. The drainage component of the street improvement project was altered to direct runoff into the flood control/recreation facility. Because this innovation reduced the cost of the street-improvement project, $90,000 of federal and state transportation funds were directed to the city to pay for some of the design and construction costs associated with the outlet control.

Figure 8.21 illustrates some features of the site. The facility functions year-round as a popular place for active and passive recreation. The facility occasionally performs its flood control function, as shown in Figure 8.22.

Figure 8.21
These photos suggest the active and passive recreation activities available within the flood control/recreation facility.
(Stuart Walesh)

Figure 8.22
When needed, the facility provides downstream flood control, as it did in August 2014.
(Stuart Walesh)

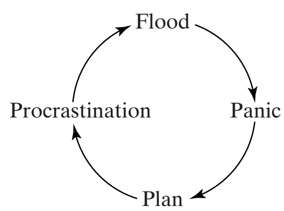

Figure 8.23
Offsetting the hydroillogical cycle, representing the likelihood of public apathy, may require creative/innovative communication and other measures.
Source: Adapted from Cyre and Shearer 1987.

8.7.5 Offsetting the Public's Short Memory

Reflect on an added benefit of a multipurpose project: Experience indicates that interest in flood control facilities rises and falls with the flood waters. If the detention facility described here had been for the single purpose of flood control, community interest may not have been sustained, in spite of the public information efforts, at a high enough level to see the project through to implementation.

During and shortly after a flood or similar rare and disastrous natural event, political leaders with public encouragement are willing to take action, at least in the form of engineering planning and design efforts. However, months later, when the engineering is completed and costly recommendations are made, political and public interest often wanes and little or nothing is done (Walesh 1989). This common aspect of flood-related public works projects is summarized as the "hydroillogical" cycle (Cyre and Shearer 1987), illustrated in Figure 8.23; offsetting it may require creative/innovative means. In the case of the previously described project, the detention facility's recreation features, some of which would be available year-round, were publicized and helped to broaden and sustain community interest, including finding ways to finance the project. Therefore, the project moved promptly ahead and, in fact, is used every day.

8.7.6 State Legislation

Partly because of a suggestion by the project's consulting engineer, the city engineer and a local state legislator took the lead in seeking state legislation to provide any Indiana municipality or similar entity with the option of establishing a storm water management utility. This type of utility enables a community to charge a fee for storm water management services, as it does for water, wastewater, and other services, and to use such funds to solve existing flooding problems and prevent development of new ones. Typically, the fee is based on some indicator of the amount of runoff generated by each property. The legislation, innovative for Indiana and prompted by engineers, was adopted in 1988. As of 2015, Indiana had thirty-nine storm water management utilities, including Valparaiso.

8.7.7 Lessons Learned

The preceding description of the planning, design, finance, and construction of a multipurpose storm water management facility offers the following insights for an engineering student or practitioner, especially one inclined to be creative and innovative:

- Apply your creative/innovative instincts to all aspects of your project, not just the technical aspects, as important as they always are. The described project included innovative engineering, innovative finance and, the frosting on the cake, innovative legislation.
- Don't assume others share your inclination to explore creative/innovative options; most don't. Accordingly, do what you can early on in any project to set the stage for possible creativity and innovation, as was done with the engineering guidelines on the storm water project. Try to dispel a *business as usual, let's do it as we always have* project atmosphere by what you say, write, and do.
- Recognize and value your knowledge and experience, and use it to initiate and influence creative/innovative local, state, and national policy and legislation.
- Anticipate the public's short memory and creatively and innovatively keep elected officials, community leaders, and the public at large engaged with an appropriate strategy, such as favoring multipurpose projects.

8.8 CONCLUDING THOUGHTS: WHAT PROFESSION DOES MORE FOR HUMANITY?

From the beginning of this book-writing project, I committed to finding and including many examples of creative/innovative products, processes, structures, facilities, and systems and noting their benefits. The examples were drawn from within and outside of engineering and include both technical and nontechnical developments. As explained in the Preface, "This strong examples/benefits thread is intended to inspire you to work smarter and to achieve even higher levels of creativity and innovation in all aspects of your current studies and later in your professional, personal, family, and community lives, as well as other activities."

However, as I approached the end of the book-writing effort, I gradually realized that something was missing: this chapter. To drive home my message about the need to be even more creative and innovative and how to do it, I needed to provide you, the engineering student or practitioner, with some more in-depth accounts of technical and nontechnical creativity and innovation drawn from a wide spectrum of engineering specialties. After all, this is mostly a book about engineering for engineers.

I have always been proud to be an engineer, especially in the *we will figure out a way to do it* sense. However, after what I learned by researching and writing this chapter—and it presents only the tiniest part of the tip of the engineering creativity/innovation iceberg—I am even more proud of our profession. Engineer, humanitarian, and thirty-first US president Hoover said: "It is a great profession. There is the fascination of watching a figment of the imagination emerge through the aid of science to a plan on paper … Then it elevates the standards of living and adds to the comforts of life. That is the engineer's high privilege." What profession does more for humanity?

> It is not very important whether engineering is called a craft, a profession, or an art; under any name this study of man's needs and of God's gifts that may be brought together is broad enough for a lifetime.
>
> —*Hardy Cross, engineering professor*

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EXERCISES

Notes:

1. The goal of the exercises is to provide students, working alone or as a team, the opportunity to think about and use the ideas, principles, and information offered in the chapter.
2. However, many circumstances and corresponding teaching/learning opportunities may arise. For example, a stated situation may be altered to meet specific concerns or needs.

8.1 ORIGINS OF A CREATION/INNOVATION IN YOUR SPECIALITY: This chapter describes in some depth a sampling of creative/innovative results drawn from six widely varying engineering specialties. Maybe your chosen or potential specialty was omitted, or perhaps you related to one of the specialties, but the creative/innovative entity did not resonate with you and others. Regardless, here is an opportunity to explore some aspect of your, or your group’s, chosen or potential specialty. The purpose of this exercise is to enable you or you and your group to further explore that specialty while learning more about creative/innovative processes.

Suggested tasks are as follows:

a. Select a structure, facility, system, product, or process from within your chosen or potential specialty that you admire and that at least seems to reflect creativity or innovation. Perhaps it drew you to the study of engineering.

b. Conduct research and then write a report that cites all sources (e.g., websites, reference books, published articles or papers, experts) and answers questions such as the following:

- Why do you admire what you selected?
- Who (individual or team) is credited with the original idea?
- What motivated the creative/innovative effort? That is, what were the circumstances? Stated differently, what issue, problem, or opportunity (IPO) was being addressed?
- How did the creative/innovative idea arise? For example, can you discover that the individual or team followed some systematic process (like those described in Chapters 4 and 7 of this book), is the process unknown, or did the idea simply “appear”?
- What obstacles were encountered and how were they overcome?
- What was the duration of the effort from concept to completion?
- What kinds of experts participated?
- What other resources were required (e.g., finance, legal, prototyping, testing) to implement the creative/innovative idea?
- What lessons did you learn?

8.2 FROM DISABLED TO SUPERABLED: Neuroprostheses (Section 8.4), now in their infancy, offer marvelous enhanced quality-of-life possibilities for individuals with various physical disabilities. As with most new technologies, neuroprosthetic applications will expand exponentially, as will the number of beneficiaries. One of the likely results is that some individuals or groups of similar individuals will transition from disabled to "superabled" (Wilson 2012). Working as a team, discuss possible superabled situations and their societal implications. For example, consider superabled athletes and superabled scholars. Use Mind Mapping to get started on this exercise. As you discover possible conflicts and controversies, generate potential resolutions using tools such as Brainstorming, the group form of Stream of Consciousness Writing, and What If.