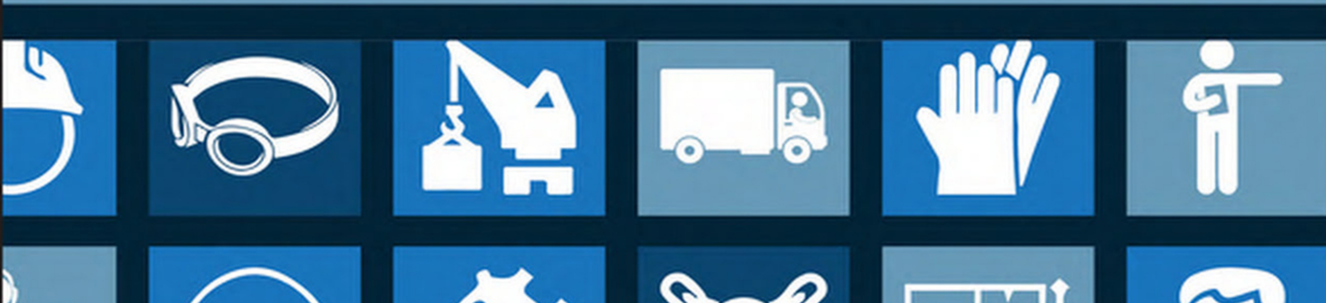
LEE T. OSTROM   CHERYL A. WILHELMSEN

RISK ASSESSMENT

TOOLS, TECHNIQUES, AND THEIR APPLICATIONS

SECOND EDITION



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CHAPTER 4

Ecological Risk Assessment

4.1 INTRODUCTION

Widespread ecological disasters are nothing new on Earth. The Earth has experienced countless natural disasters over its history. One of the first disasters that could most likely be the first step in progress toward current life forms on Earth is the advent of oxygen. Oxygen-producing organisms began spewing free oxygen into the atmosphere around 2.45 billion years ago (1). This free oxygen oxidizes iron, and the resulting iron oxide precipitated out to the floors of the oceans. It thus removed the dissolved iron from the oceans. These iron deposits are still mined today (2, 3). Maybe if those cyanobacteria or blue–green algae had not released free oxygen into the atmosphere, there would be some other forms of life on Earth.

The Earth has also had ice ages that have covered the entire globe or a major portion of the northern or southern hemisphere with ice, thus reducing the space that organisms could live to either in the depths of oceans or on land closer to the equator. The Earth has experienced hot, moist periods of time that allowed for the proliferation of new plant and animal species that drastically changed the environment. In fact, what is amazing is that the Earth remained habitable by some form of life for hundreds of millions of years.

Plants and animals, in general, have the tendency to destroy their living environment as they consume the resources they need to live. The production of alcohol by yeast in the manufacture of beer and wine is an excellent example of the cycle of an organism (4). Yeast converts sugars to alcohol. Once the alcohol level in a fermentation vat reaches somewhere between 4 and 12%, depending on the variety of the yeast, they shut down production due to the change in the environment. The growth

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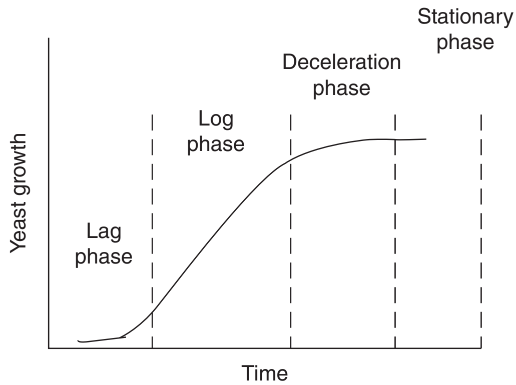

FIGURE 4.1 Yeast growth.

of the yeast has four distinct phases:

1. Lag Phase – yeast matures and acclimates to the environment.
2. Log or Expediential Phase – yeast rapidly multiplies, consuming resources and generating waste and alcohol.
3. Deceleration Phase – yeast growth slows due to lack of resources, sugar, and too much waste in the environment, alcohol.
4. Stationary Phase – limited growth occurs due to lack of resources and too much waste.

Yeasts literally eat themselves out of their environment. Figure 4.1 shows the four phases of yeast growth.

Algae blooms in aquatic environments, overpopulation of deer in protected areas, and the lemming and predator balance in the Arctic are all examples of similar observable ecological disasters in which animals or plants have a specific role.

Humans, of course, cause ecological disasters of their own. Those of us who grew up in the 1950s, 1960s, and 1970s still remember vividly the ecological problems that abounded in the United States during those decades. In north Idaho, for instance, the Silver Valley around Kellogg, ID, was under a constant layer of acrid smoke due to the lead smelters in the area. Driving from Coeur d'Alene, ID, to Kellogg, one would go from blue skies into a cloud of acrid smoke within a matter of 30 miles. Trees could not grow on the mountain sides due to the chemicals contained in the cloud of pollution. When vacationers ski in the Silver Valley today, they see very few remnants of the ecological disaster that once were blatantly obvious. The hillsides are once again tree covered and the air is relatively clean. However, lead levels remain high in the soil and on the bottom of Lake Coeur d'Alene (5). The primary operator of the lead smelters was Bunker Hill. The area around the Bunker Hill site was declared an Environmental Protection Agency (EPA) Superfund Site in the early 1980s and a great mount has been put into cleaning up the area.

More famous, or infamous, ecological disasters include:

- Chernobyl, Soviet Union (Belarus and Ukraine)
- Bhopal, India
- Deepwater Horizon, United States
- Love Canal, United States
- Minamata Methylmercury, Japan
- Agent Orange, Vietnam and the United States
- Seveso, Italy
- Jilin plant explosion

In this book we have discussed the Bhopal and Chernobyl events in several chapters. The following will discuss the attributes of the other events listed.

4.1.1 Deepwater Horizon

In the late spring and summer of 2010, the United States was dealing with one of the worst oil spills ever (6–8). It occurred in the Gulf of Mexico and involved the Deepwater Horizon drilling platform. The Deepwater Horizon was an offshore oil platform owned by Transocean Ltd. (Transocean). The rig was drilling within the Macondo Prospect oil field approximately 50 miles southeast of Mississippi in approximately 5000 ft of water. The Deepwater Horizon was considered an ultra-deepwater, dynamically positioned, column-stabilized, semi-submersible mobile offshore drilling unit (MODU) and could operate in waters of up to 8000 ft deep. Semi-submersibles are rigs that have platforms with hulls, columns, or pontoons that have sufficient buoyancy to cause the structure to float, but with weight sufficient enough to keep the structure upright. The Deepwater Horizon housed 126 workers, and its task was to drill wells and extract and process oil and natural gas from the Gulf of Mexico and export the products to shore. As with any large venture, there are several principle players in an oil exploration and development process. The rig was owned by Transocean, but the principal developer of the Macondo Prospect oil field was British Petroleum Company (BP). The Horizon had been leased to BP on a three-year contract for deployment in the Gulf of Mexico following its construction. On 20 April 2010, an explosion on the Deepwater Horizon, and its subsequent sinking two days later, resulted in the largest marine oil spill in the history of the United States and the deaths of 11 workers.

On 20 April 2010, at 10:45 p.m. EST, a sudden explosion rocked the Deepwater Horizon oil platform. The resulting fire traveled so fast that survivors stated they had less than five minutes to evacuate the platform after the first fire alarm. Most of the workers had to evacuate the platform by using the lifeboats from an auxiliary ship, the M/V Damon B Bankston. The Bankston had been hired to service the large platform oil rig. After the evacuation, eleven persons remained unaccounted for, and rescue procedures were put into place.

The US Coast Guard launched a rescue operation involving two cutters, four helicopters and a rescue plane. The Coast Guard conducted a three-day search covering approximately 5300 miles. They called off the search for the missing persons, concluding that the "reasonable expectations of survival" had passed. "Officials concluded that the missing workers may have been near the blast and not been able to escape the sudden explosion" (7). After many investigations, it has been suggested that the cause of the explosion and resulting fire was that a bubble of methane gas escaped from the well and rose up through the pipes, expanding and blowing out seals and barriers as it rose before exploding on the oil rig.

The Deepwater Horizon had been tethered to the ocean floor by a pipe used to extract oil called a riser. Because of the platform's sinking, the pipe was damaged. The damaged pipe began leaking a tremendous amount of oil in what is commonly known as a "gusher." Huge quantities of crude oil gushed from the riser pipe for approximately three months. A device called a blowout preventer (BOP) attached to the pipe at the ocean floor level to prevent such an occurrence failed to operate. Numerous attempts to manually operate the BOP also failed. The rate of oil that was released from the riser soon became a hotly debated issue. Real-time video feeds from the scene played out all over the United States and, in fact, the world to see. Eventually the resulting oil spill would cover almost 30 000 miles^2 of ocean and an area, depending on weather conditions, larger than the state of South Carolina. The inaccuracies concerning the amount of oil release from government responders directly conflicted with the estimates of nongovernment scientists who suggested that the oil release figures were being grossly underreported. Though, in reality, the exact quantity of oil released was really not the issue. The real issue was how to clean up the oil that was there and, subsequently, preventing future occurrences. The most reliable estimate of the amount of oil that was released was "roughly five million barrels of oil were released by the Macondo well, with roughly 4.2 million barrels pouring into the waters of the Gulf of Mexico" (7).

BP's attempts to plug the leak had become a long and arduous task. BP engineers' initial plan was to use remotely operating underwater vehicles (ROV) to stop the leak by remotely activating the BOP, which was "a massive five story, 450 ton stack of shut-off valves, rams, housings, tanks and hydraulic tubing that sits on top of the well" (7, 8). As previously stated, the BOP failed to operate and speculation was that gas hydrates entered and formed in the BOP after a methane bubble rose up through the riser and blew out the seals and barriers in the pipes causing it to malfunction.

BP's next and subsequent attempts had become exercises in futility. On 7 May, BP engineers decided it would use a "top hat" or cofferdam to control the escaping oil from the broken riser. A top hat is a containment dome that is maneuvered over a blowout to collect the escaping oil so that it can be funneled through a pipe up to an awaiting drill ship on the surface. Except this top hat was 98 tons of steel. This project soon floundered because again, "the cofferdam containment system failed, becoming iced up with methane hydrates when hydrocarbons from the end of riser proved to have a higher gas content than anticipated" (9). A second smaller top hat that weighed a mere 2 tons and had the ability to be injected with alcohol to act as an antifreeze to reduce the formation of gas hydrates was the next course of action, but that plan was abandoned on 12 May, when engineers became unsure that plan would work either. “The first significant success at reducing the release of oil came on May 17, 2010 when robots inserted a four-inch diameter Riser Insertion Tube Tool (RITT) into the Horizon’s riser, a twenty one-inch diameter pipe between the well and the broken end of the riser on the seafloor in five-thousand feet of water” (7). The RITT is supposed to work like a giant straw that siphons off the leaking oil and transports it to an awaiting tanker on the surface. This attempt brought some success.

The company’s long-range plan was to initiate relief wells that would intercept the bored out well at approximately 13 000 ft below the ocean floor. After the relief wells were completed, heavy fluids and cement could be pumped down the damaged hole to kill the well; this is referred to as a “top kill.” The only problem with this plan is it would take a minimum of 90 days to accomplish. Thus the reasoning for the stopgaps put into play was to reduce the oil leak at the broken riser early on after the explosion. On 25 May, the RITT was disabled for a “top kill” procedure scheduled for the following day.

> On May 26, 2010, the U.S. government gave BP the approval to proceed with a ‘top kill’ operation to stop the flow of oil from the damaged well. The procedure was intended to stop the flow of oil and gas from the damaged well and ultimately kill it by injecting heavy drilling fluids through the BOP. On May 29, 2010, BP engineers said that the ‘top kill’ technique had failed. Over thirty thousand barrels of heavy mud was injected into the well in three attempts at rates of up to 80 barrels a minute. Several different bridging materials had been tried and still the operation did not overcome the flow from the well (7).

After 86 days and several failed attempts and efforts to seal the leak, on 15 July, BP succeeded in stopping the flow of oil into the Gulf of Mexico.

Much of the work on oil platforms has become automated in its functions below the waves and on the ocean floor. But human error still manifests itself from time to time on these huge sea-going structures. These drilling rigs are some of the largest moveable man-made structures in the world; as such they have become virtual cities afloat that will always have minor equipment failure and human error, not to mention working in hurricane-prone environments. The Deepwater Horizon was no different; it had a long history of spills, fires, and other mishaps before the Gulf oil spill in April of 2010. There is even a collision documented in its recent history.

> Because vessels like the Deepwater Horizon operate 24 hours a day, Coast Guard officials said minor equipment problems appear frequently. If these problems are not corrected then such incidents could mushroom into bigger concerns (10).

The agency responsible for investigating the safety of offshore and gas operations is the US Department of the Interior’s Minerals Management Service (MMS). The MMS had an extensive, detailed inspection program to help ensure the safety of offshore oil and gas operations. MMS inspectors are placed offshore on oil and gas

drilling rigs and production platforms to audit operator compliance with extensive safety and environmental protection requirements.
The Deepwater Horizon had experienced many problems before.

- In 2005 the oil rig, still under contract with BP, "spilled 212 barrels of an oil based lubricant due to equipment failure and human error. That spill was probably caused by not screwing the pipe tightly enough and not adequately sealing the well with cement, as well as a possible poor alignment of the rig, according to records maintained by the federal Minerals Management Service" (10). Following that spill, MMS inspectors recommended increasing the amount of cement used during this process and applying more torque when screwing in its pipes.
- Also in 2005, a crane operator sparked a hazardous fire aboard Deepwater Horizon while refueling. His inattention caused diesel to overflow, and a spark initiated a fire on board. "In June 2003, the rig floated off course in high seas, resulting in the release of 944 barrels of oil. MMS blamed bad weather and poor judgment by the captain."
- "A month later, equipment failure and high currents led to the loss of an additional 74 barrels of oil" (10). These were just a few of the mishaps that were reported, and investigated by the MMS on the Deepwater Horizon before the blowout on April 2010.

The MMS, the caretaker of America's federal lands and oceans and watchdog of the oil and gas drilling industry, had come under increasing criticism in the years prior to the Deepwater Horizon mishap. "Investigators from the Interior Department's inspector general's office said more than a dozen employees, including the former director of the oil royalty-in-kind program, took meals, ski trips, sports tickets and golf outings from industry representatives. The report alleges that the former director, Gregory W. Smith, also netted more than $30,000 from improper outside work" (11). The collection of billions of dollars in royalties from oil and gas companies by government officials in their capacity were also alleged to have taken bribes, the steering of contracts to favored clients, and engaging in illicit sex with employees of the energy firms. In the report, investigators said they "discovered a culture of substance abuse and promiscuity" in which employees accepted gratuities "with prodigious frequency" (11).

The responsibility for the initial cleanup was assumed by BP oil corporation. Tony Haywood, Chief Executive Officer (CEO), formally verbalized to the American people that his company was taking full responsibility for the disaster "and where people can present legitimate claims for damages we will honor them." To augment the cost of the cleanup, under the Federal Water Pollution Control Act, the Oil Spill Liability Trust Fund (OSLTF), established in the Treasury helped defer expenses of a federal response to oil pollution and to help compensate claims for oil removal and damages as authorized by the Oil Pollution Act of 1990 (OPA). "The OPA requires that responsible parties pay the entire price tag for cleaning up after spills from offshore drilling, including lost profits, destroyed property and lost tax revenue, but the statute caps their liability for economic damages at $75 million. Aggressive collection efforts are consistent with the 'polluter pays' public policy underlying the OPA. BP and Transocean have been named as responsible parties, although all claims are still being processed centrally through the BP Corporation" (7).

Many events led to the explosion on the Deepwater Horizon platform. Numerous events took place that contributed to the disaster. Working at great depths, 5000 ft or more, and pressures greater than 2000 lb in^{-2} (13 789 514.56 Pa) should be re-evaluated. Problems at these depths have very real dangers and are unfamiliar. Most equipment used to secure a well run amok has only been tested at depths half that of the Deepwater Horizon's. Guy Cantwell, a spokesman for the oil rig's owner, Transocean Ltd., said that the Swiss-based company planned to conduct its own investigation of what caused the explosion aboard the Deepwater Horizon. "The industry is going to learn a lot from this. That's what happens in these kinds of disasters," he said, citing a 1988 explosion of the Piper Alpha rig in the North Sea and a 1979 blowout of Mexico's IXTOC I in the Eastern Gulf (10). After the North Sea incident in which 167 men were killed, Great Britain revamped its safety requirements concerning deepwater drilling. There is no doubt that the same will happen in the United States. Numerous "well topping" devices and associated installation accessories have already been designed, built, and readied for future deployment, particularly where gas hydrates are concerned. It seems as though deepwater drilling is here to stay.

As of the writing of this book, we are only one year since this event occurred. There is still much controversy as to the long-term effects of the spill. Only time will tell what the long-term ecological effects of the spill are.

4.1.2 Love Canal

In 1920 Hooker Chemical (Hooker) had turned an area in Niagara Falls into a municipal and chemical disposal site (12–14). In 1953 the site was filled and relatively modern methods were applied to cover the disposal site. A thick layer of impermeable red clay sealed the dump. The idea was that the clay would seal the site and prevent chemicals from leaching from the landfill.

A city near the chemical disposal site wanted to buy it for urban expansion. Despite the warnings made by Hooker, Niagara Falls School Board eventually bought the site for the amount of $1. Hooker could not sell for more, because they did not want to earn money off a project. As part of the development process, the city began to dig to develop a sewer. This damaged the red clay cap. Blocks of homes and a school were built, and the neighborhood was named Love Canal.

Love Canal seemed like a normal, regular neighborhood. The only thing that distinguished this neighborhood from others was the strange chemical odors that often hung in the air and an unusual seepage noticed by inhabitants in their basements and yards. Children in the neighborhood often became sick. Love Canal families regularly experienced miscarriages and birth defects.

Lois Gibbs, an environmental activist, noticed the high occurrence of illness and birth defects in Love Canal and started documenting it. In 1978 newspapers revealed the existence of the chemical waste disposal site in the Love Canal area and Lois Gibbs started petitioning for closing the local school. In August 1978, the claim succeeded and the NYS Health Department ordered the closing of the school when a child fell ill from a chemical poisoning.

When the waste site at Love Canal was assessed, the researchers found over 130 lb of the highly toxic carcinogenic 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD), a form of dioxin. A total of 20 000 tons of waste present in the landfill appeared to contain more than 248 different types of chemicals. The waste consisted of pesticide residues and chemical weapons research refuse, along with other organic and inorganic compounds.

Due to the breach of the clay cap, chemicals had entered homes, sewers, yards, and waterways and more than 900 families had to be relocated. President Carter provided federal funds to move all the families to a safer area. Hooker's parent company was sued and settled for $20 million.

Even though most of the chemicals were not removed from the chemical disposal site and despite protests by Gibbs's organization, some of the houses in Love Canal went up for sale some 20 years later. The site was resealed and the surrounding area was cleaned and declared safe. Today a barbed wire fence isolates the worst area of the site from the areas that are not as contaminated. Hooker's mother company paid an additional $230 million to finance this cleanup. They are now responsible for the management of the dumpsite. Today, the Love Canal dumpsite is known as one of the major environmental disasters of the century. Bacteria and other microbes might eventually break down the organic materials into safer compounds, but this could take hundreds, if not thousands, of years.

4.1.3 Minamata Methylmercury

The Chisso Corporation first opened a chemical factory in Minamata, Japan, in 1908 (15, 16). Initially producing fertilizers, the factory followed the nationwide expansion of Japan's chemical industry, branching out into production of acetylene, acetaldehyde, acetic acid, vinyl chloride, and other chemicals. The Minamata factory became the most advanced chemical company in Japan in the 1930s and 1940s. The waste products resulting from the manufacture of these chemicals were, as in many chemical and other process industries, released right into Minamata Bay. As with any chemical put into the environment, these pollutants had an impact, such as damaging the fisheries. In response, Chisso reached two separate compensation agreements with the fishery cooperative in 1926 and 1943 (16).

The Chisso Minamata factory was very successful and it had a very positive effect on the local economy (15). The area lacked other industry and, Chisso had great influence in Minamata. Over half of the tax revenue of Minamata City came from Chisso and its employees, and the company and its subsidiaries were responsible for creating a quarter of all jobs in Minamata.

The Chisso Minamata factory first started acetaldehyde production in 1932, producing 210 tons that year. Acetaldehyde is used as a chemical intermediary in the production of numerous products, for instance, vinyl. By 1951 production had jumped to 6000 tons per year and reached a peak of 45 245 tons in 1960 (16) The Chisso factory's output amounted to between a quarter and a third of Japan's total acetaldehyde production. The chemical reaction used to produce the acetaldehyde used mercury sulfate as a catalyst. A side reaction of the catalytic cycle led to the production of a small amount of an organic mercury compound, namely, methylmercury (17). This highly toxic compound was released into Minamata Bay from the start of production in 1932 to 1968. Interestingly enough, elemental mercury is poorly absorbed through the skin or through ingestion. However, the vapors of elemental mercury are much more hazardous. Methylmercury is very hazardous, as compared with elemental mercury. In 1968 the production process was modified and mercury was no longer used.

On 21 April 1956, a five-year-old girl was examined at the Chisso Corporation's factory hospital in Minamata, Japan, a town on the west coast of the southern island of Kyūshū. The physicians were puzzled by her symptoms: difficulty in walking, difficulty in speaking, and convulsions. Two days later her younger sister also began to exhibit the same symptoms and she too was hospitalized. The girls' mother informed the doctors that her neighbor's daughter was also experiencing similar problems. After a house-to-house investigation, eight further patients were discovered and hospitalized. On 1 May, the hospital director reported to the local public health office the discovery of an "epidemic of an unknown disease of the central nervous system," marking the official discovery of Minamata disease (15).

Researchers from Kumamoto University began to focus on the cause of the strange disease. They found that the victims, often members of the same family, were clustered in fishing hamlets along the shore of Minamata Bay. The staple food of victims was invariably fish and shellfish from Minamata Bay. The cats in the local area, who tended to eat scraps from the family table, had died with symptoms similar to those now discovered in humans. This led the researchers to believe that the outbreak was caused by some kind of food poisoning, with contaminated fish and shellfish being the prime suspects.

On 4 November, the research group announced its initial findings: "Minamata disease is rather considered to be poisoning by a heavy metal … presumably it enters the human body mainly through fish and shellfish" (16).

As soon as the investigation identified a heavy metal as the causal substance, the wastewater from the Chisso plant was immediately suspected as the origin. The company's own tests revealed that its wastewater contained many heavy metals in concentrations sufficiently high to bring about serious environmental degradation including lead, mercury, manganese, arsenic, selenium, thallium, and copper. Identifying which particular poison was responsible for the disease proved to be extremely difficult and time consuming. Between 1957 and 1958, many different theories were proposed for the cause of the ailments. Initially manganese was thought to be the causal substance due to the high concentrations found in fish and the organs of the deceased. A theory that there were multiple contaminants involving thallium and selenium was proposed. In March 1958, visiting British neurologist Douglas McAlpine suggested that the symptoms shown by victims in Minamata resembled those of organic mercury poisoning. From that point forward, the focus of the investigation centered on mercury.

In February 1959, the mercury distribution in Minamata Bay was investigated. The results showed that large quantities of mercury were detected in fish, shellfish, and sludge from the bay. At the mouth of the wastewater canal, there was approximately 2 kg of mercury per ton of sediment. This level would be economically viable to mine. Chisso did later set up a subsidiary to reclaim and sell the mercury recovered from the sludge (16).

Fifty years later, the legacy of Minamata Bay lives on. Victims still receive payment for their injuries and methylmercury still persists in the environment.

4.1.4 Agent Orange

Agent Orange was the code name for one of the herbicides and defoliants used by the US military as part of its herbicidal warfare program during the Vietnam War (18, 19). The campaign called Operation Ranch Hand involved spraying the countryside with the chemicals with the goal of defoliating the jungles and destroying crops.

Agent Orange was a 50:50 mixture of 2,4,5-T and 2,4-D (20). It was manufactured for the US Department of Defense primarily by Monsanto Corporation and Dow Chemical. The 2,4,5-T used to produce Agent Orange was later discovered to be contaminated with TCDD, an extremely toxic dioxin compound. It was given its name from the color of the orange-striped 55 US gal (200 l) barrels that were shipped in (18). It was the most widely used herbicide during the war.

During the Vietnam War, between 1962 and 1971, the US military sprayed nearly 20 000 000 US gal (75 700 000 l) of chemical herbicides and defoliants in Vietnam, eastern Laos, and parts of Cambodia, as part of the operation (18, 19).

Air Force records show that at least 6542 spraying missions took place over the course of the operation (18). Approximately 12% of the total area of South Vietnam had been sprayed with defoliating chemicals by the end of the war. It is estimated to be up to 13 times the recommended USDA application rate for domestic use (21). In South Vietnam an estimated 10 million ha of agricultural land was affected (19). In some areas TCDD concentrations in soil and water were hundreds of times greater than the levels considered “safe” by the US Environmental Protection Agency (EPA) (19, 21). Overall, more than 20% of South Vietnam’s forests were sprayed at least once over a nine-year period (21).

The legacy of the spraying during the war lives on. Approximately 17% of the forested land had been sprayed, and to this day dioxins contained in the chemicals remain in the soil. In many places the natural foliage has been replaced by invasive plant species. Animal species diversity was also significantly impacted. For instance, a Harvard biologist found 24 species of birds and 5 species of mammals in a sprayed forest, while in two adjacent sections of unsprayed forest, there were 145 and 170 species of birds and 30 and 55 species of mammals (22).

Movement of dioxins through the food web has resulted in bioconcentration and biomagnification (23). The areas most heavily contaminated with dioxins are the sites of former US air bases (18). The Vietnam Red Cross reported as many as 3 million Vietnamese people have been affected by Agent Orange, including at least 150 000 children born with birth defects (24).

The problem with dioxins is that they are highly toxic, with no safe levels of exposure, and the chemicals take a tremendous amount of time to break down (25). This class of chemicals is produced as a by-product of producing chemicals for legitimate use or when chlorinated chemicals are burned. Vietnam is not the only place in the world where dioxins pose a threat. Seveso, Italy, experienced an environmental issue due to dioxin.

4.1.5 Seveso, Italy

During the middle of the day on 10 July 1976, an explosion occurred in a 2,4,5-trichlorophenol (TCP) reactor in the ICMESA chemical company in Meda, Italy (26, 27). A cloud containing toxins escaped into the atmosphere. The cloud contained high concentrations of TCDD. Downwind from the factory, the dioxin cloud polluted a densely populated area of 6 km long and 1 km wide, immediately killing many animals. Seveso is a neighboring municipality that was highly affected. The dioxin cloud affected a total of 11 communities.

Even though the media includes Seveso when other major disasters such as Bhopal and Chernobyl are discussed, the Seveso story is different when it comes to handling the toxins (26). Polluted areas were researched after the release and the most severely polluted soils were excavated and treated elsewhere. Health effects were immediately recognized as a consequence of the disaster and victims were compensated. A long-term plan of health monitoring was also put into place. Seveso victims suffered from a directly visible symptom known as chloracne and genetic impairments (27).

The Seveso accident and the immediate reaction of authorities led to the introduction of European regulation for the prevention and control of heavy accidents involving toxic substances. This regulation is now known as the Seveso Directive, which became a central guideline for European countries for managing industrial safety.

The most remarkable feature of the Seveso accident was that local and regional authorities had no idea the plant was a source of risk (26). The factory existed for more than 30 years and the public had no idea of the possibility of an accident until 1976. The European Directive was created to prevent such ignorance in the future and to enhance industrial safety. The Council of Ministers of the Council of Europe adopted the directive in 1982. It obligates appropriate safety measures and also public information on major industrial hazards, which is now known as the "need-to-know" principle (27).

4.1.6 Jilin Chemical Plant Explosion

This particular incident had impacts on both the environment and regional conflict. This account was adapted from the Environmental Justice Atlas (28). On 13 November 2005, an explosion at a petrochemical plant in China's northeastern Jilin province resulted in the release of 100 tons of toxins into the Songhua River. Much of the notoriety of the 2005 Songhua spill was derived from the flawed response capability exhibited by central and regional state authorities. On 26 November, representatives from China's State Environmental Protection Administration (SEPA) visited both the UN Environmental Program (UNEP) in Nairobi and the United Nations offices in Beijing to provide extensive data on the Songhua spill, after which SEPA continued to send regular updates to the United Nations. Although a decisive move on the part of the Chinese state, it approached the United Nations only after the pollution slick had reached Harbin, a full two weeks following the initial explosion in Jilin province. Harbin is an industrial city of 10 million people, with three major universities. While the central government went public largely because it could no longer keep information on the incident from its own citizens, it is perhaps safe to assume that this was the longest the Chinese government could wait without risking confrontation with Russia, whose border lay downriver (29).

Underlying China's delayed response at the international level was an almost paralyzing confusion at local and domestic levels. In the immediate aftermath of the explosion on 13 November, factory officials denied that pollutants had entered the Songhua River. It was five days before SEPA issued emergency monitoring instructions to its provincial counterpart, the Heilongjiang Province Environmental Protection Bureau (EPB). During those five days, it appears that factory officials together with local government officials attempted to manage the spill themselves without notifying Beijing, going so far as to drain reservoir water into Songhua River in an attempt to dilute the contaminants. Even after the central government intervened on 18 November, it failed to notify the general public of the danger until the slick reached Harbin. In the intervening period, public rumor regarding an undefined public emergency proliferated. Several days before the spill reached Harbin, city officials shut down municipal water services, citing a need to repair the system's facilities (29).

Following the central government's announcement, the domestic media was filled with material regarding the spill. Many of these articles traced the chain of responsibility and cover-up leading back to the explosion, in the process implicating high-ranking officials first in Jilin and later in Harbin. At this time the international media and international environmental groups also became closely involved, following the domestic media's lead in focusing on the dangerous lack of public information surrounding the spill. Even the UNEP team was invited to help evaluate the situation on the Songhua

River in December 2005. The initial field report generally approved of the Chinese government's response to the disaster, noted that the lack of public information management posed an avoidable danger, and indicated a lack of centralized emergency response procedures (29).

State media reported that five people were killed in the explosion only a few hundred meters from the river bank. Up to 10 000 people were temporarily evacuated. "We will be very clear about who's responsible," said Zhang Lijun, deputy director of SEPA, at a news conference in Beijing. "It is the chemical plant of the CNPC in Jilin Province." Zhang did not elaborate, but he said an investigation would be considered if there was any criminal liability for the spill. The official Xinhua news agency reported that the company had apologized for the contamination.

The company "deeply regrets" the spill and would take responsibility for handling the consequences, said CNPC's deputy general manager, Zeng Yukang. The vice governor of Jilin province, Jiao Zhengzhong, also apologized to the people of Harbin, according to a report Thursday in the newspaper Beijing News (30).

"Harbin's move to cut off the water supply was not a knee-jerk reaction," said Zhang Lanying, an environmental expert from Jilin University.

"If the contaminated water had been supplied to households, the result would have been unimaginable." Apart from the danger to the Chinese population and environment, the spill could also have diplomatic repercussions as it heads toward the point where the Songhua River joins the Heilongjiang River, which then crosses the Russian border in the region of Khabarovsk, about 550 km downriver from Harbin (29).

The longer-term environmental consequences of the Chinese spill are unknown. Environmental and other groups have suggested that the food chain in the river basin and corresponding region could be affected for some time. At the time, the Times (United Kingdom) reported on 21 December 2005 that fishing in the area could be banned for as long as four years. Other articles have suggested that the benzene contamination could present a long-term problem in that it can bioaccumulate in the basin's organisms, remain trapped in river ice that will melt and result in additional releases, and become trapped in the river's sediments (28).

4.1.7 Risk of Ecological Disasters

Unfortunately, the risk of another man-made ecological disaster looms just around the corner. The dumping of the reactor cores from nuclear-powered ships into the Barrett Sea by the Russian military and the other legacy nuclear sites in Russia and other former Soviet Union Republics pose a significant potential threat to the environment. In addition, many manufacturers in developing countries are displaying the same lack of environmental concern that developed countries had in the early to late 1900s. The resulting polluted bodies of water and land have the potential to cause widespread environmental problems. In addition, even well-run companies can have a process upset that results in a chemical spill that could cause catastrophic harm to the environment (31).

4.1.8 Ecological Risk Assessment

Ecological risk assessment (ERA) is a process that is used to help determine what risks are posed by an industry, government, or other entity. It further provides a logical process to help eliminate or mitigate such threats.

An ERA evaluates the potential adverse effects that human activities have on the living organisms (plants and animals) that make up ecosystems. The risk assessment process provides a way to develop, organize, and present scientific information so that it is relevant to future and present environmental decisions. When conducted for a particular place such as a forest or wetland, the ERA process can be used to identify vulnerable and valued resources, prioritize data collection activity, and link human activities to their potential effects. ERA results provide a basis for comparing different management options, enabling decision makers and the public to make better informed decisions about the management of ecological resources (32).

As EPA guidance states, ERAs are used to support many types of management actions, including the regulation of hazardous waste sites, industrial chemicals, and pesticides, or the management of watersheds or other ecosystems affected by multiple nonchemical and chemical stressors. The ERA process has several features that contribute to effective environmental decision making (32, 33):

- Through an iterative process, new information can be incorporated into risk assessments that then can be used to improve environmental decision making.
- Risk assessments can be used to express changes in ecological effects as a function of changes in exposure to stressors. This capability may be particularly useful to decision makers who must evaluate tradeoffs, examine different alternatives, or determine the extent to which stressors must be reduced to achieve a given outcome.
- Risk assessments explicitly evaluate uncertainty. Uncertainty analysis describes the degree of confidence in the assessment and can help the risk manager focus research on those areas that will lead to the greatest reductions in uncertainty.
- Risk assessments provide a basis for comparing, ranking, and prioritizing risks. The results can also be used in cost–benefit and cost-effectiveness analyses that offer additional interpretation of the effects of alternative management options.
- Risk assessments consider management goals and objectives as well as scientific issues in developing assessment endpoints and conceptual models during problem formulation. Such initial planning activities help ensure that results will be useful to risk managers.

The ERA approach contained in this book follows the EPA's guidelines (32). However, a search of the literature does present many other similar processes that can be used to assess ecological risk (33).

According to the EPA, the ERA process is based on two major elements:

1. Characterization of effects
2. Characterization of exposure

These provide the focus for conducting the three phases of risk assessment:

1. Problem formulation
2. Analysis
3. Risk characterization

Figure 4.2 shows the overall flow of an ERA.

The three phases of risk assessment are enclosed by a dark solid line.

Problem formulation is the first phase. During problem formulation, the purpose for the assessment is developed, the problem is defined, and a plan for analyzing and characterizing risk is also developed. Initial work on problem formulation includes the integration of available information on potential sources of contaminates, potential stressors to the environment, potential effects, and ecosystem and receptor characteristics. From this information two products are generated: assessment endpoints and conceptual models. Either product may be generated first (the order depends on the type of risk assessment), but both are needed to complete an analysis plan, the final product of problem formulation (32).

Analysis follows problem formulation. During the analysis phase, data are evaluated to determine how exposure to potential environmental stressors is likely to occur (characterization of exposure) and, if an exposure were to occur, the potential and type of ecological effects that could be expected (characterization of ecological effects). The first step in analysis is to determine the strengths and limitations of data on potential exposures, potential effects, and ecosystem and receptor characteristics. The products from these analyses are two profiles, one for exposure and one for stressor response. These products provide the basis for risk characterization (32, 33).

As part of the risk characterization phase, the potential exposure and stressor response profiles are integrated through the risk estimation process. Risk characterization includes a summary of assumptions, scientific uncertainties, and strengths and limitations of the analyses. The final product is a risk description in which the results of the integration are presented, including an interpretation of ecological adversity and descriptions of uncertainty and lines of evidence (33).

As with all risk assessments, ERAs are iterative in nature, as new data becomes available. For instance, in some cases, the health effects of chemicals are not fully elucidated until after the chemical or product has been in use.

4.1.9 Ecological Risk Assessment in Practice

The following will provide an example of how an ERA can be conducted. Note that all the information concerning organizations, locations, and scenarios have been

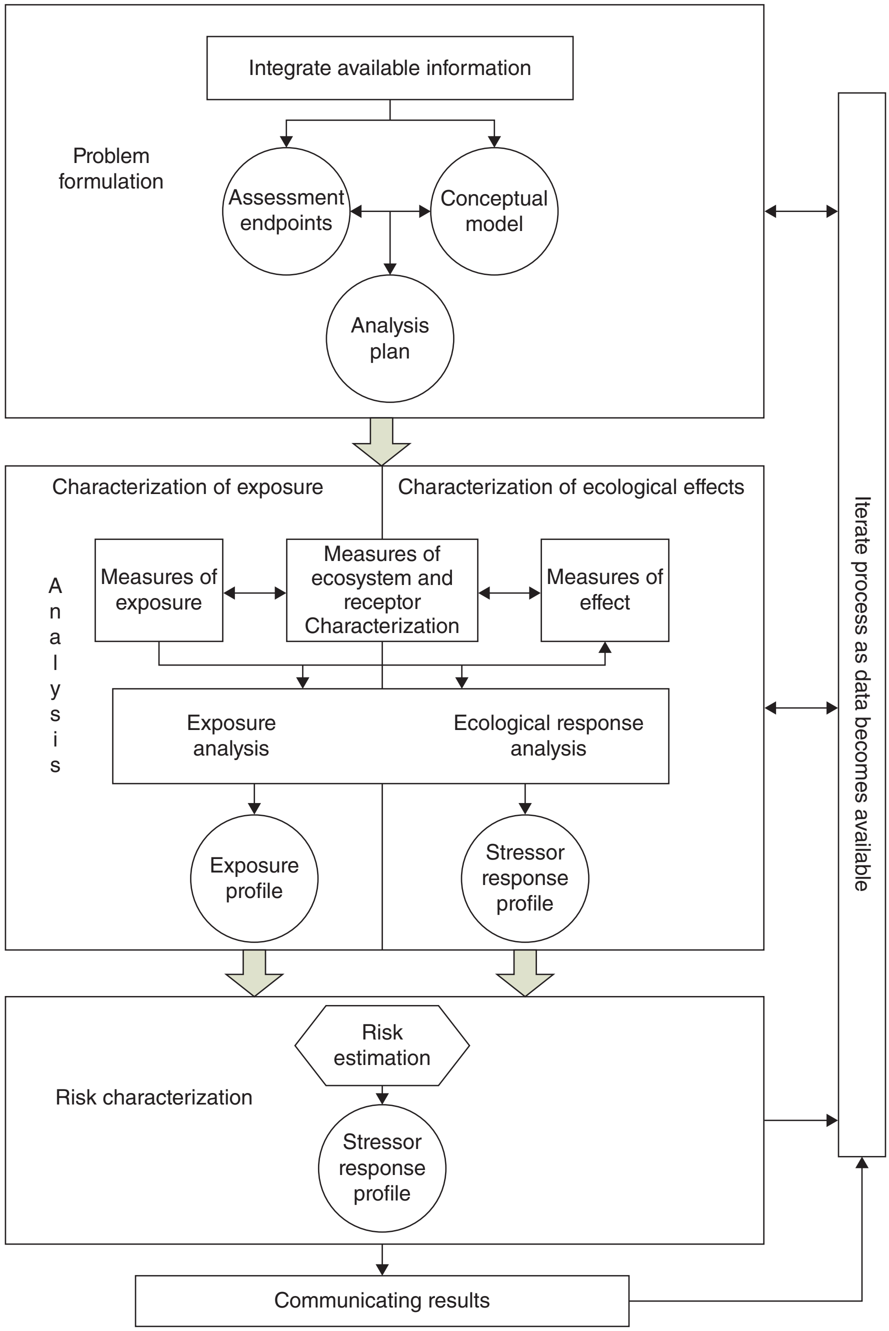

FIGURE 4.2 Ecological risk assessment process flow *Source*: Adapted from EPA (32).

fabricated. The nature of the chemicals are factual, but the information provided is for illustration only and not for reference. Also, this is not an exhaustive ERA, only an example one.

4.1.10 Production Plant, Inc.

Production Plant, Inc. (PPI) has been in the widget manufacturing business for 25 years. The product they manufacture is Widget A (WA). It is a stable product for the company and PPI plans on producing these widgets for the foreseeable future. In this regard, PPI is planning an expansion into a West Coast state so that they can serve the Pacific Rim countries better. The plot of land they are proposing to build on is approximately 20 acres and borders the Great River on one side, and the land contains a small creek that only flows during early winter until midsummer. Figure 4.3 shows the general layout and the proposed building location of the property. It also shows the flows of the waterways.

The proposed building site was used before as a farmland, and the farm-related chemicals found in the soil are shown in Table 4.1.

However, testing of Little Creek reveals that none of the farm chemicals are leaching into the waterway under current conditions.

The land generally slopes toward the Great River. There is a 10-ft elevation difference between the north end of the property and where it borders the river. At the

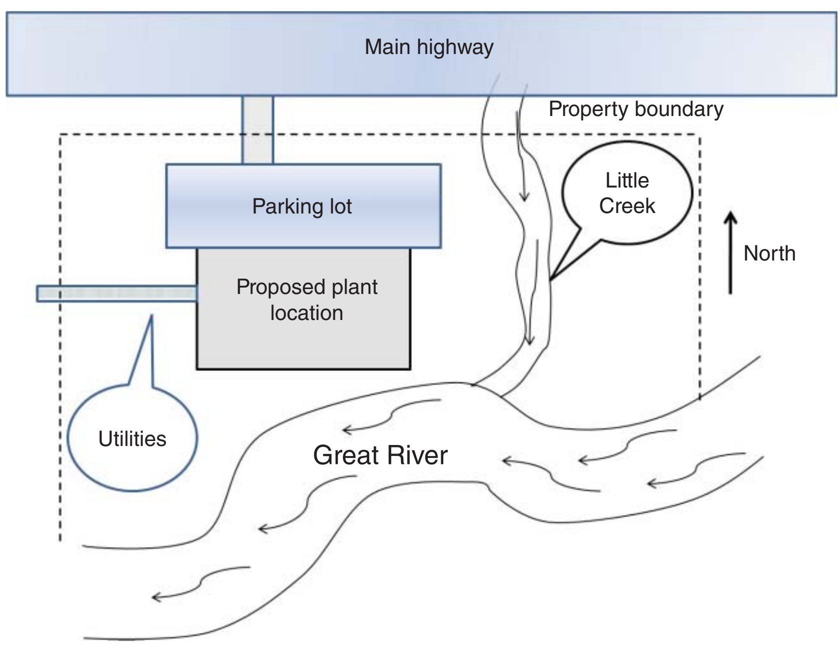

FIGURE 4.3 Proposed layout of PPI west coast location.

TABLE 4.1
Farm Chemicals Found in the Soil on Proposed Building Site

Product	Level detected	LC_{50}[a] ($mg\,l^{-1}$)	LD_{50}[b] ($mg\,kg^{-1}$)
Organophosphate A	50 ppb	0.1	10
Thiocarbamate C	1 ppm	20	25
Herbicide H	0.5 ppm	5	7
Fungicide X	10 ppb	100	120

[a]LC50 is lethal concentration for 50% of the population.
[b]LD50 is lethal dose to 50% of the population.

river's edge, there is a 10-ft drop off from the property to the river for most of the year. During spring runoff this decreases to 1–2 ft. The current vegetation consists of sage brush and nonnative grasses/weeds. Some bushy plants are found in Little Creek. The animals currently observed on the site are voles and gophers, raccoons near Little Creek, and several bird species, including great horned owls. The Great River contains a wide range of fishes, including sturgeon, white fish, rainbow trout, and largemouth bass. There are also several mollusks and crustaceans living in the river. Little Creek contains no fish because it is dry for most of the year. Some frog species enter the creek during wet periods.

The proposed land development process will entail digging up an area (140 ft by 100 ft) for the proposed building's foundation. The soil will remain on site. The building will not have a basement, but the soil will need to be removed to a depth of 2 ft so that the foundation slab will be level. Therefore, approximately 28 000 ft^{-3} of soil will be disturbed.

The building process will consist of bringing in pre-poured concrete slabs and erecting in place. A further land area of 5000 ft^{-2} will be disturbed by the erection equipment. An area of 180 ft by 100 ft will also be paved for a parking lot. Therefore, ultimately an area of 32 000 ft^{-2} of the 86 000 total square footage of the land will be no longer available to absorb rainwater and snowmelt.

The soil that will be excavated for the building site will be landscaped into rolling mounds on the south side of the building. The mounds and land disturbed by the building process will be planted with native vegetation once the building process is complete.

The utilities for the proposed factory will consist of electrical lines, potable water, natural gas, and ethanol that will be supplied from a neighboring plant. There will be three normal waste streams:

- Normal sewage waste from the toilets and shower areas – 20 000 gal per day
- Wash water containing biodegradable solvents and cleansers – 1000 gal per day
- Process water containing ethanol, methanol, and trace amounts of copper metal – 500 gal per day. This will be stored in a tank for pickup.

TABLE 4.2
Chemicals Used to Manufacture Widget A

Chemical	Proposed quantity on site	Usage volume	Hazardous nature	LD_{50}[a]
Copper sulfate	1000 lb	10 lb per day	Moderately toxic	300–470 mg kg^{-1} (rat and mammals)
Aluminum Chloride	2000 lb	100 lb per day	Corrosive and moderately toxic	380 mg kg^{-1} (rat)
Ethanol	No onsite storage – supplied via pipeline	20 000 gal per day	Flammable, low toxicity	6300 mg kg^{-1} (rabbit)
Methanol	1000 gal stored on site	50 gal used per day	Flammable, moderate to low toxicity	5600 mg kg^{-1} (rat)

[a]These values are provided for example only and not for reference. Please consult the specific material safety data sheet (MSDS) for correct toxicity data.

It is proposed that the normal sewage will be discharged into the city system. It is proposed that the wash water be proposed on site by means of a digester. The process wastewater contains enough process chemicals that a local company might be interested in obtaining it and reprocessing it to remove the valuable contents.

The process for producing WA involves utilizing the chemicals shown in Table 4.2.

The Great River is 200 yards wide and 50 ft deep as it passes the proposed plant site. It discharges into the Pacific Ocean 100 miles below the proposed site. 100 000 people live below the plant site, along the Great River.

4.1.11 Problem Formulation

As per the EPA's ERA guidance, the first step in the process of assessing the impact of the proposed PPI plant is to develop the problem formulation. In this regard, the potential sources of contaminants need to be identified. The potential sources of containments from the proposed PPI plant include:

- Farm chemicals leaching out from the soil due to soil disturbance
- Spills from
  - Process upsets
  - Leaks from the ethanol supply line
  - Leaking process storage tanks and bins
  - Leaking process waste tank
  - Delivery trucks
  - Wastewater digester
  - Cleaning chemical spills

The assessment endpoints for this sample ERA that will be discussed are as follows:

- Reduction in species richness or abundance or increased frequency of gross pathologies in fish communities resulting from toxicity.
- Reduced richness or abundance of native plant species due to the establishment of the plant.
- Reduction in abundance or production of terrestrial wildlife populations resulting from toxicity.

The ecological assessment endpoints were selected based on meetings that included representatives of the local EPA, PPI, state department of environmental quality, and county planners.

1. The fish community in the Great River is considered to be an appropriate endpoint community because it is ecologically important and has a scale appropriate to the site.
2. The native plant life is considered to be an appropriate endpoint community because of its ecological importance and due to the amount of space the proposed PPI site will occupy.
3. The animal community is considered to be an appropriate endpoint community because it is ecologically important and due to the potential number of small mammals and birds that might be displaced by the PPI site.

This example ERA will consider the following measurement endpoints:

4.1.12 Fish

Single Chemical Toxicity Data – Chronic toxicity thresholds for freshwater fish are expressed as chronic EC20s or chronic values. These test endpoints correspond to the assessment endpoints for this community.

4.1.13 Terrestrial Plants

Biological Survey Data – Quantitative plant survey data does exist for the native and nonnative plants on the proposed plant site.

4.1.14 Terrestrial Animals

Single Chemical Toxicity Data – These include acute and chronic toxicity thresholds for contaminants of concern in birds and mammals with greater weight given to data from long-term feeding studies with wildlife species.

4.1.15 Conceptual Model

Conceptual models are graphical representations of the relationships among sources of contaminates, ambient media, and the endpoint biota. Suter (34, 35) has developed a complete guide on developing conceptual models for ERAs. Figure 4.4 is an example conceptual model that would be appropriate for the ERA for the proposed PPI plant.

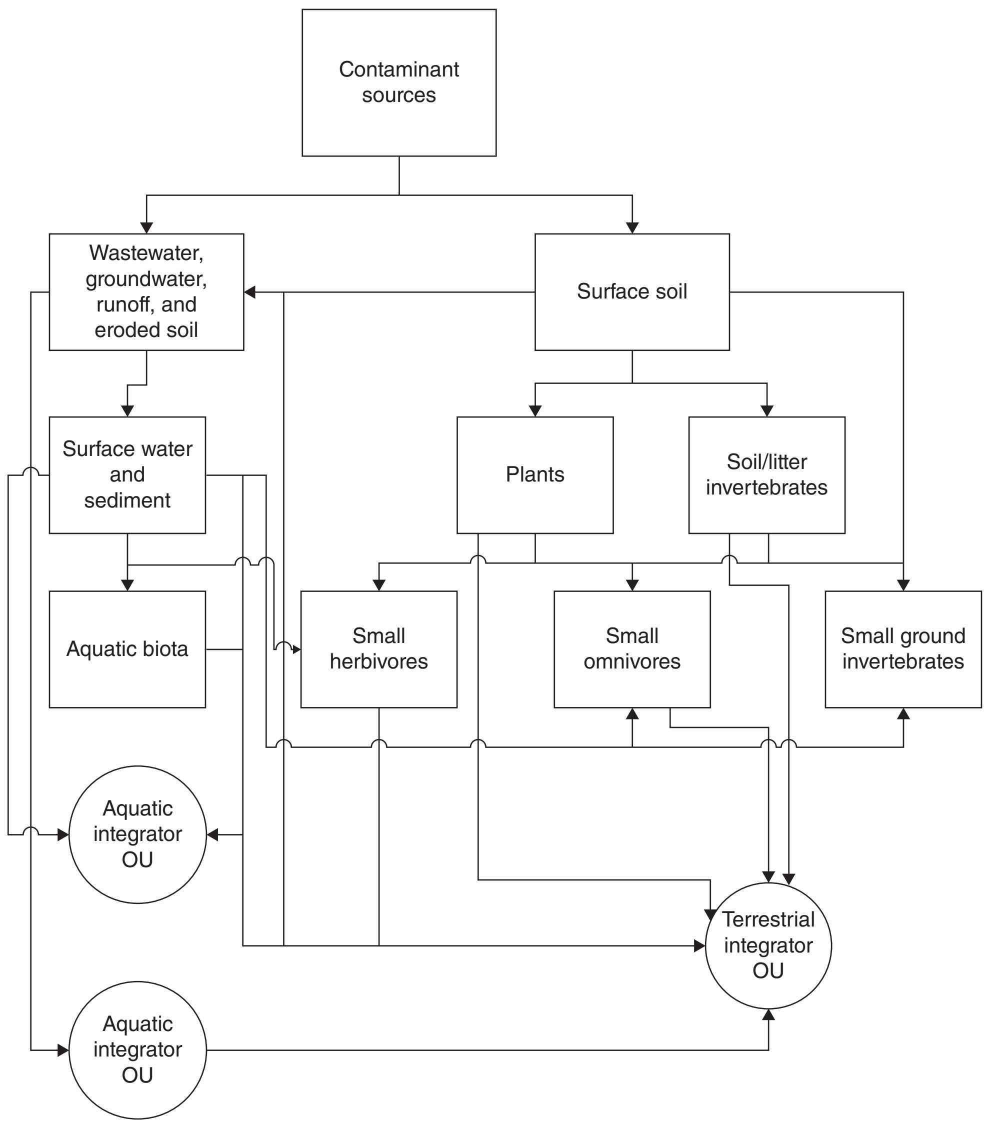

FIGURE 4.4 Example conceptual model for proposed PPI plant *Source*: Adapted from Suter (35).

In this ERA the three areas that will be assessed are the impact on fish in the Great River, the native plants growing on the proposed PPI plant site and the area that will be disturbed by the construction of the building and parking lot, and the animals inhabiting the PPI property.

4.1.16 Analysis Plan

The analysis plan for the PPI ERA follows the problem formulation. Therefore, in this example the analysis plan will concern the fish in the Great River, the terrestrial plants, and the terrestrial animals. These analyses can be very involved and demanding. In this example only a sampling of the types of analyses will be presented. In this regard, a partial analysis of the risk to fish will be presented.

4.1.17 Risks to Fish

In this partial analysis, the risk to fish will be examined to a limited degree. The fish are potentially exposed to contaminants in their natural environment, water. The contaminants in the water could come from upstream of the proposed plant, from the 30 communities that discharge treated water from sewage disposal plants, from farm runoff, from permitted and nonpermitted industrial plant discharge locations, and from military bases. The contaminants that potentially harm fish from the proposed PPI plant include the runoff from the ground that contained the farm chemicals. It could come from a process upset and a resulting spill of the industrial chemicals. It could come from a spill from a delivery truck and from something like an employee's vehicle leaking fuel tank or oil leak. In a full ERA, the following analyses would be performed:

- The aqueous chemical exposure model.
- Fish chemical exposure burdens.
- Toxicity tests – determining how various exposures could affect fish species.

These analyses can be quite involved and result in data that will be used in the decision making concerning the design of the plant. Because the proposed plant is to be located in an area that has had a large amount of farm chemicals applied to the soil, the potential fish body burden of farm chemicals in the fish population might already be high. It might then be considered that water runoff from the proposed plant would not pose a further significant health risk to the fish. However, since the construction of the plant will disrupt the soil, there could be a much higher potential to release the chemicals into the waterways via runoff.

As an example, the analysis found that the fish in the Great River already carry a high body burden of farm chemicals, especially Herbicide H. Addition of more chemicals into the river could harm not only the fish but also birds who feed on the fish.

4.1.18 Risk Characterization

Risk characterization is the final phase of an ERA and is the culmination of the planning, problem formulation, and analysis of predicted or observed adverse ecological effects related to the assessment endpoints. Completing risk characterization allows decision makers to clarify the relationships between stressors, effects, and ecological entities and to reach conclusions regarding the occurrence of exposure and the adversity of existing or anticipated effects. The analysts performing the ERA use the results of the analysis phase to develop an estimate of the risk posed to the ecological entities included in the assessment endpoints identified in problem formulation, in this case, fish in the Great River, terrestrial plants, and terrestrial animals. After estimating the risk, the assessor describes the risk estimate in the context of the significance of any adverse effects and lines of evidence supporting their likelihood. Finally, the analysts identify and summarize the uncertainties, assumptions, and qualifiers in the risk assessment and reports the findings to decision makers.

Since this is a proposed plant, the ERA could be used to help design the plant site to avoid or eliminate any threat found. For instance, it is apparent that disrupting the soil has the potential of releasing farm chemicals from soil. The analysis found that the fish already carry a high body burden of these chemicals. Therefore, something needs to be done to eliminate or reduce to the level possible the amount of chemicals that could be released from the soil. How can this be accomplished? Several things could be done:

- Remove the soil from the site and placing it in an approved landfill.
- Lay a clay pad first and then putting the excavated soil on the pad and then placing a clay berm around the site to contain the water runoff from the soil.
- Place a dike below the proposed site and collecting all the water runoff and processing it to remove the pesticides.

A cost–benefit analysis would need to be performed to help choose the best solution.

The ERA would then be updated to reflect the changes in the plant design.

For instance, if the proposed chemicals were changed so that they posed less of an ecological risk, then that aspect of the ERA would be modified. An example of this would be the elimination of the copper sulfate as a process chemical. A safer process using something other than copper sulfate would significantly reduce the ecological risk posed by this plant. The goal, as with every risk assessment, is to reduce the risk, in this case, the ecological risk.

4.2 SUMMARY

An ERA is a very systematic and very scientifically intensive analysis. In this chapter an abbreviated example was presented that provides an example of the types of analyses that are performed as a part of an ERA. Experienced ERA analysts should be employed to perform such an analysis to ensure every aspect of the ERA is performed appropriately.

Self-Check Questions

1. Ecological risk assessment is an analysis more difficult to conduct than other types of risk assessments. Provide five reasons why it is more difficult to conduct.
2. Why is the most sensitive organism used as the basis of an ecological risk assessment?
3. Pick an ecological disaster and explain how it could have been prevented.
4. Pick an ecological disaster and explain the long lasting effects of the disaster. These might be political or ecological.
5. What happened to the oil from the Deepwater Horizon event?
6. Heavy metal contamination in many ways is more hazardous to the environment than hydrocarbon contamination. Why?

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Acronyms

AFM	acute flaccid myelitis
AMTs	aviation maintenance technicians
ANSI	American National Standards Institute
APU	auxiliary power unit
ASEP	Accident Sequence Evaluation Program
ATHEANA	A Technique for Human Error Analysis
BA	British Airways
BES	Bulk Energy System
BLS	Bureau of Labor Statistics
BP	British Petroleum
BTU	British thermal unit
CAHR	Connectionism Assessment of Human Reliability
CAMEO	Computer-Aided Management of Emergency Operations
CFPB	Consumer Fraud Protection Bureau
CFR	Code of Federal Regulations
CHRIS	Chemical Hazards Response Information System
CIMA	Chemical Industry Mutual Aid Organization
CIT	Critical Incident Technique
COOP	Continuity of Operations Plan
COSO	Committee of Sponsoring Organizations of the Treadway Commission
CPSC	Consumer Product Safety Commission
CREAM	Cognitive Reliability and Error Analysis Method
CSB	Chemical Safety Board
CSRF	cross-site request forgery
D&D	decontamination and decommissioning
DDoS	distributed denial of service
DOE	Department of Energy

Risk Assessment: Tools, Techniques, and Their Applications, Second Edition. Lee T. Ostrom and Cheryl A. Wilhelmsen.

Companion website: www.wiley.com/go/Ostrom/RiskAssessment_2e

DOS	denial of service
DVI	detailed visual inspection
ECCS	emergency core cooling system
ECL	energy conservation loop
EFIS	electronic flight instrument system
EM	emergency management
EMA	Emergency Management Agency
EPA	Environmental Protection Agency
EPZ	emergency planning zones
ERA	ecological risk assessment
ERG	Emergency Response Guidebook
ERM	enterprise risk management
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FMC	flight management computer
FMEA	failure mode and effects analysis
FMECA	failure mode, effects, and criticality analysis
FTA	fault tree analysis
FW	feed water
GDPR	General Data Protection Regulation
GEM	generic error modeling
GPS	Global Positioning System
GVI	general visual inspection
HAZMAT	hazardous materials
HAZOP	hazard and operability study
HEPs	human error probabilities
HERMIT	human error modeling/investigation tool
HEROS	human error rate assessment and optimizing system
HRA	human reliability analysis
IoT	Internet of things
IRGC	International Risk Governance Council
IRM	integrated risk management
IRMs	intermediate range monitors
ISO	International Organization for Standardization
LED	light-emitting diode
LOCA	loss-of-coolant accident
LPG	liquid petroleum gas
MITM	man in the middle
MMS	Minerals Management Service
MOC	management of change
MRO	maintenance, repair, and overhaul
MS	mode switch

MSDS	material safety data sheet
MTBF	mean time between failures
MTTF	mean time to failure
NARA	nuclear action reliability assessment
NASA	National Aeronautics and Space Administration
NDE	nondestructive examination
NDT	nondestructive testing
NRC	Nuclear Regulatory Commission
NSC	National Safety Council
NTSB	National Transportation Safety Board
OEM	original equipment manufacturer
OF	operational factor
OPA	Oil Pollution Act
OSHA	Occupational Safety and Health Administration
PHA	preliminary hazards analysis
PHZA	process hazard analysis
P&ID	piping and instrumentation
PM	periodic maintenance
POD	probability of detection
PPE	personal protective equipment
PPI	Production Plant, Inc.
PPID	positive perceived indication of damage
PRA	probabilistic risk assessments
PRM	project risk management
PSA	probabilistic safety assessments
PSF	performance shaping factor
PSM	process safety management
RAT	ram air turbine
RBS	risk breakdown structure
RCP	reactor coolant pump
RCRA	Resource Conservation and Recovery Act
RMP	risk management plan
SCADA	supervisory control and data acquisition
SCRAM	safety control rod axe man
SME	subject matter experts
SPAR-H	Simplified Plant Analysis Risk Human Reliability Assessment
SRM	source range monitor
STA	shift technical advisor
STEM	science, technology, engineering, and math
TAT	threat assessment team
TCDD	2,3,7,8-tetrachlorodibenzo-*p*-dioxin
THEA	Technique for Human Error Analysis

THERP	Technique for Human Error Rate Prediction
VPP	Voluntary Protection Program
WBS	work breakdown structure
WHO	World Health Organization
WVPP	workplace violence prevention programs
XSS	cross-site scripting

Glossary

Accident An unexpected and undesirable event, especially one resulting in damage or harm.

Acetaldehyde An organic chemical compound.

Acute flaccid myelitis (AFM) A rare but serious condition. It affects the nervous system, specifically the area of the spinal cord called gray matter, which causes the muscles and reflexes in the body to become weak.

Anomalies Deviation or departure from the normal or common order, form, or rule.

Autobiography Written by the individual himself or herself.

Basic event A fault or failure in an accident sequence that can occur, which has an impact on the overall outcome or the top event of a probabilistic risk assessment or fault tree analysis.

Bayesian analysis A statistical procedure that endeavors to estimate parameters of an underlying distribution based on the observed distribution.

Bioconcentration Uptake and accumulation of a substance from water alone.

Biographical study A study where the researcher writes and records the experiences of another person's life.

Biomagnification The increase in concentration of a substance such as the pesticide DDT.

BlackEnergy A malware program.

Boundary conditions The values or conditions that constrain a system.

Case study research A qualitative approach in which the investigator explores a bounded system (a case) or multiple bounded systems (cases) over time, through detailed, in-depth data collection involving multiple sources of information (e.g. observation interviews, audiovisual material, and documents and reports), and reports a case description and case-based themes.

Chloracne An acne-like eruption of blackheads, cysts, and pustules.

Closed loop Materials do not enter or leave a system.

Component System, job/person, part, tool, or other thing that performs the activities that make up the critical function.

Component failure An electronic or mechanical part of a system that ceases to work. In risk assessment terms, this unit has an impact on the success or failure of a system.

Risk Assessment: Tools, Techniques, and Their Applications, Second Edition. Lee T. Ostrom and Cheryl A. Wilhelmsen.

Companion website: www.wiley.com/go/Ostrom/RiskAssessment_2e

Component fault An electronic or mechanical part of a system that ceases to work or ceases to work correctly. In risk assessment terms, this unit has an impact on the success or failure of a system.

Conditional probability A probability whose sample space has been limited to only those outcomes that fulfill a certain condition.

Consequences The positive or negative outcomes of decisions, events, or processes.

Critical function What has to be in place to achieve or maintain the mission.

Critical Incident Technique A technique that has applicability to a wide range of risk assessments.

Cryptocurrency Digital or virtual currency.

Cut set A set of basic events that lead to the top event in a probabilistic risk assessment or fault tree.

Cybercrime Vandalism, theft, fraud, extortion, data ransom, phishing.

Cyberterrorism Nation-state conducted or sponsored threats.

Delphi process A structured communication technique, originally developed as a systematic, interactive forecasting method, which relies on a panel of experts.

Dengue fever A painful, debilitating mosquito-borne disease caused by any one of four closely related dengue viruses. These viruses are related to the viruses that cause West Nile infection and yellow fever.

Discrete distribution A statistical distribution that has specific values.

DoS attack The ability to interrupt the smart grid systems. This is called a denial of service.

Ebola virus disease A rare and deadly disease most commonly affecting people and nonhuman primates (monkeys, gorillas, and chimpanzees). It is caused by an infection with a group of viruses within the genus *Ebolavirus*.

Emerging risks A high level of uncertainty, in which frequency and potential impact of risks are difficult to assess. An emerging risk is typically characterized by a low frequency or, in other words, not likely to happen and has a high impact.

Enterprise risk management The process of planning, organizing, leading, and controlling the activities of an organization in order to minimize the effects of risk on an organization's capital and earnings.

***Escherichia coli* (*E. coli*)** Bacteria that normally live in the intestines of healthy people and animals. Most varieties of *E. coli* are harmless or cause relatively brief diarrhea. But a few particularly nasty strains, such as *E. coli* O157:H7, can cause severe abdominal cramps, bloody diarrhea, and vomiting.

Ethnographic research This study describes learned and shared patterns of the group's behaviors, beliefs, and language.

Event tree A graphical representation of the possible sequence of events that might occur following an event that initiates an accident.

Failure mode and effects analysis (FMEA) A detailed document that identifies the ways in which a process or product can fail to meet critical requirements. It is a living document that lists all the possible causes of failure from which a list of items can be generated to determine types of controls or where changes in the procedures should be made to reduce or mitigate risk.

Failure mode, effects, and criticality analysis (FMECA) The additional dimension of probability and criticality added to FMEA(s) by the prioritization of steps/sections of procedures that need to be changed or the process changed to reduce risk; pointing out where warnings, cautions, or notes need to be added in procedures; and pointing out where special precautions need to be taken or specialized teams/individuals need to perform tasks. The criticality is mainly a qualitative measure of how critical the failure to the process really is based on subject matter experts' opinion and based on probability of occurrence and/or on the consequence or effect.

Fault tree analysis A form of safety analysis that assesses hardware safety to provide failure statistics and sensitivity analyses that indicate the possible effect of critical failures.

Gates Logic structures in a fault tree that connect basic events.

Grounded theory research Generates, or discovers, a theory.

Hazard Any risk to which a worker is subject to as a direct result (in whole or in part) of his/her being employed.

Hazmat Hazardous materials.

HAZOP A hazard and operability study is a structured and systematic examination of a complex planned or existing process or operation in order to identify and evaluate problems that may represent risks to personnel or equipment.

Hierarchical task analysis A broad approach used to represent the relationship between the tasks and the subtasks.

Human reliability analysis (HRA) Used to analyze the human response to an equipment failure and any process or activity that involves humans is susceptible to human error. HRAs are used to quantify the probability of human errors and can be used to identify steps or activities in the process that can be targeted for changes that could reduce the probability of human error.

HVAC Heating, ventilation, and air conditioning.

Hydrazine A colorless, fuming, corrosive hygroscopic liquid, H_2NNH_2, used in jet and rocket fuels.

Intelligent automation Machine learning, robotic process automation, which complements and augments human skills that can increase speed, precision, quality, and operational efficiency.

Internet of things (IoT) Artificial intelligence and robotization.

Involuntary risks Those associated with activities that happen to us without our prior consent or knowledge. Acts of nature such as being struck by lightning, fires, floods, tornados, and so on and exposure to environmental contaminants are examples of involuntary risks.

Link analysis Identifies the relationships between the components of a system and represents the links between those components.

Methylmercury A bioaccumulative environmental toxicant.

Minamata disease A neurological syndrome caused by severe mercury poisoning.

Mission Goal of process, organization, or task.

Monte Carlo analysis One specific multivariate modeling technique that allows researchers to run multiple trials and define all potential outcomes of an event or investment.

Nanoparticle A small object that behaves as a whole unit in terms of its transport and properties.

Narrative research A method in how and why we make meaning in our lives, a way to create and recreate our realities.

Newton's First Law Every action has an equal or greater reaction.

Nomenclature The terminology used in a particular science, art, activity, and so on.

Nominal value The value of a security that is set by the company issuing it, unrelated to market value.

Operations sequence diagrams Identifies the order in which the tasks are performed and identifies the relations between the person, equipment, and the time.

Oral history A compilation of events and causes, found in folklore, private situations, and single or multiple episodes.

Perception The process of interpreting sensory stimuli by filtering it through one's experiences and knowledge base.

Phenomenological description A phenomenological study describing the meaning for several individuals of their lived experiences of a concept or a phenomenon.

Preliminary hazard analysis A hazard analysis performed at the very beginning of a product or facility life cycle to determine the hazards.

Preliminary hazards list Hazards initially determined from an analysis.

Probabilistic risk assessment (PRA) Focuses on equipment failures and may include a section that discusses the probability of human failure being the initiating event.

Probability The likelihood that the event will occur.

Process mapping A technique that produces visual representations of the steps involved in industrial or other processes.

Process risk management It is the process used by project managers to minimize any potential problems that may negatively impact a project's timetable.

Process safety management A set of interrelated approaches to **managing** hazards associated with the **process** industries and is intended to reduce the frequency and severity of incidents resulting from releases of chemicals and other energy sources.

Qualitative analysis Nonquantitative analysis. An analysis that is descriptive in nature.

Qualitative research Methods that at least attempt to capture life as it is lived.

Quantitative analysis An analysis that seeks to determine the numerical value of something.

Reverse engineer The process of discovering the technological principles of a man-made device, object, or system through analysis of its structure, function, and operation. It often involves taking something (e.g. a mechanical device, electronic component, or software program) apart and analyzing its workings in detail to be used in maintenance or to try to make a new device or program that does the same thing without using or simply duplicating (without understanding) any part of the original.

Risk The potential for realization of unwanted, adverse consequences to human life, health, property, or the environment; estimation of risk is usually based on the expected value of the conditional probability of the event occurring times the consequence of the event given that it has occurred.

Risk analysis A detailed examination, including risk assessment, risk evaluation, and risk management alternatives, performed to understand the nature of unwanted, negative consequences to human life, health, property, or the environment; an analytical process to provide information regarding undesirable events; the process of quantification of the probabilities and expected consequences for identified risks.

Risk assessment The process of establishing information regarding acceptable levels of a risk and/or levels of risk for an individual, group, society, or the environment.

Risk control The application of the risk assessment evaluation.

Risk estimation The scientific determination of the characteristics of risks, usually in as quantitative a way as possible. These include the magnitude, spatial scale, duration, and intensity of adverse consequences and their associated probabilities as well as a description of the cause and effect links.

Risk evaluation A component of risk assessment in which judgments are made about the significance and acceptability of risk.

Risk homeostasis theory In any activity, people accept a certain level of subjectively estimated risk to their health, safety, and other things they value, in exchange for the benefits they hope to receive from that activity (transportation, work, eating, drinking, drug use, recreation, romance, sports, or whatever).

Risk identification Recognizing that a hazard exists and trying to define its characteristics. Often risks exist and are even measured for some time before their adverse consequences are recognized. In other cases, risk identification is a deliberate procedure to review and, it is hoped, anticipate possible hazards.

Risk perception An individual or group assessment of the potential for negative consequence.

Severity The degree of something undesirable.

Smart grid A new innovation of the current electric grid to provide power across our nation and the world.

Statistically nonverifiable Risks from involuntary activities that are based on limited data sets and mathematical equations.

Statistically verifiable Risks for voluntary or involuntary activities that have been determined from direct observation.

Support Utilities, materials, activities, or other items that support the components.

Target risk A specific level of risk an organization feels comfortable with and aims to achieve.

Task analysis Task analysis is any process of assessing what a user does and why, step by step, and using this information to design a new system or analyze an existing system.

Thematic analysis One of the most common forms of analysis in qualitative research. It emphasizes pinpointing, examining, and recording patterns (or “themes”) within data.

Threat Source of danger.

Threat assessment A structured group process used to evaluate the risk posed by a student or another person, typically as a response to an actual or perceived threat or concerning behavior.

Timeline analysis Used to match up the process performance over time, which includes the task frequency, interactions with the other tasks, the worker(s), and the duration of the task.

TNT Chemical compound.

TOP events The event of interest in a probabilistic risk assessment or fault tree analysis to which all other basic events feed.

Undeveloped event Events with little information or no information or those that do not need to be developed because they concern things such as weather or other natural events.

Voluntary risks Those associated with activities that we decide to undertake (e.g. driving a car, riding a motorcycle, drinking, and driving).

Vulnerability A weakness in a system or human that is susceptible to harm.

Zika virus A mosquito-borne flavivirus that was first identified in Uganda in 1947 in monkeys. It was later identified in humans in 1952 in Uganda and the United Republic of Tanzania.