CONSIDERATIONS FOR CONTROLLING UNINTENDED RELEASE OF CONTAMINANTS

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INTRODUCTION

Any project that involves the use or transport of materials has the potential to release contaminants into the environment. Cleanup of these releases (intentional or not) can be very expensive and time consuming. Developing a well thought out contaminant control process before operations begin or when changing operations can reduce the overall costs and liabilities associated with the project.

A contaminant can be defined as any substance that causes harm to humans or the environment. Two main categories include inorganic compounds (lead, mercury, nickel, chlorides, sulfates) and organic compounds (benzene, toluene, ethyl-benzene, xylene, petroleum). They can be released as gases, liquids, solids, or aerosols. Once released, they can be spread out over very large areas by wind and water. The longer a release is allowed to disperse, the larger an area it will contaminate.

No site wants to have spills, accidents, or disasters, but they can happen at even the most well-run site. This article will provide some general advice on how to reduce the chances of releasing a contaminant and to minimize the impact if one occurs.

KEYWORDS

pollution prevention, chemical safety, emissions, spill plans, risk minimization

CONTROLLING CONTAMINATION

Prevention and vigilance are the best strategies for controlling contamination. Prevention is used during design or redesign to minimize the chances of a release and to minimize the impact of a release. Vigilance is used during operation to make sure proper procedures are used; equipment is maintained; materials are tested for corrosion; and the air, water, and nearby soils are monitored and tested to catch releases when they start, as well as to minimize the number and severity of accidents.

The goals for any contaminant control process should be to: minimize uncontrolled releases; reduce transportation distances; minimize the potential area of contamination during uncontrolled/unplanned releases; reduce fugitive releases; and limit impacts from disasters (flooding, auto/truck accidents, high winds). The plan should try to maximize employee awareness and buy-in. People on the site are a main source of information about what is

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happening at the different areas of the site. They can be one of the main lines of defense in preventing and controlling contaminant releases. People can be encouraged to provide this information by having open channels for collecting such information, standard procedures (with minimal paperwork) for reporting observations, and rewards for catching potential problems. These activities should be a part of creating a safety culture at a site. People buy in to such a culture when safe activities are valued and unsafe activities are discouraged.

Contaminant prevention starts with understanding the inputs and outputs from a process.

INPUTS	**OUTPUTS**
Raw Materials	Product
Water	Waste (gases, liquids, and solids)
People	People

Knowing what materials are on a site determines the types of contamination events that could occur. The characteristics of each material and its potential to contaminate must be understood before the design and construction of the project. This understanding also helps inform operations and what sorts of hazards to be on the lookout for. For example, a solids transfer operation would monitor air for particulate matter during operations and surface water quality, especially during and after storms. An oil processing facility would be more concerned with liquid leaks that either evaporate or enter the ground and migrate toward the groundwater. Monitoring may include automated air sampling to measure ambient concentrations of volatile compounds and would follow a standard notification protocol when discoloration of the soil is observed. Any site with significant process/production water will need to monitor nearby surface waters. Solid waste must be carefully stored to prevent wind/rain erosion, with frequent air monitoring for particulates.

Oil and Gas Industry

There are three main types of contamination associated with the oil and gas industry—air pollutants, produced water, and drilling waste. Air pollutants include the criteria pollutants (NO_x, SO_2, PM, and CO) as well as various hazardous air pollutants (HAPs), volatile organic compounds (VOCs), ammonia (NH_3), and hydrogen sulfide (H_2S). Produced water originates within the oil or gas that is removed from the reservoir. It contains various salts, sodium, iron, as well as the chemicals that are used during construction and use. Drilling waste contains the mud, rock fragments, cuttings, and added chemicals. Additional potential contaminants include oily soil, tank bottoms, workout fluids, produced sand, pit and sump wastes, pigging waste, and equipment reject water. Any of these materials can be accidently released and cause a contamination event.

Mining and Mineral Processing Industry

The main types of contamination associated with the mining and processing industry include: process water, leachate, high solids water (slurry), acid mine drainage, heavy metals (lead, mercury, cadmium, arsenic), cyanide, fuel oils, sulfuric acid, and diesel exhaust. Additionally tailing ponds can be breached and cause catastrophic releases to nearby land and surface water.

CONTAMINANT SOURCES

Air Contaminants

There are three source categories for a contaminant released into the air—point source, area source, and fugitive source. Point sources are also called major sources. They are typically very closely regulated and monitored. It is unusual for these to cause contamination because great effort is put into minimizing such releases. Area sources, sometimes referred to as minor sources, are small point sources with concentrations below a regulatory threshold, but many together may make a significant contribution. These are more difficult to monitor or control since an emission location may be mobile or otherwise difficult to identify (i.e., a fuel storage tank on a portable diesel engine). Emissions from these sources are not regulated like point sources, but may require air monitoring at the site boundary. The site may also be encouraged to use best practices for controlling emissions. Fugitive sources are associated with any operation where inputs and outputs may escape in an unplanned manner—dust from a moving truck or railcar, particulates released during bulk transfer of materials, leaks from pipes, pumps, or storage tanks. They are usually intermittent or one time releases. They may not have a specific regulation other than the use of best practices. Such emissions can be overlooked unless a vigilant monitoring system is in place.

Examples

Point sources include exhaust stacks, flares, or vents. Area sources may include a cluster of buildings, a holding pond, a transfer yard, or portable electrical generating units. Fugitive sources include construction areas, evaporation from waste piles, dust generated at transfer yards, roadways, or along rail lines.

Liquid Contaminants

There are several types of liquid contaminants. How they will interact with the environment depends on their specific properties. Some of the more important properties are water solubility, volatility, and ability to wet the soil. Other important considerations include viscosity,

FIGURE 1. Fugitive emissions cannot be seen by the unaided human eye (www.engineerlive.com). Specialized cameras can identify and quantify fugitive releases of several different VOCs (www.irtconsult.com).

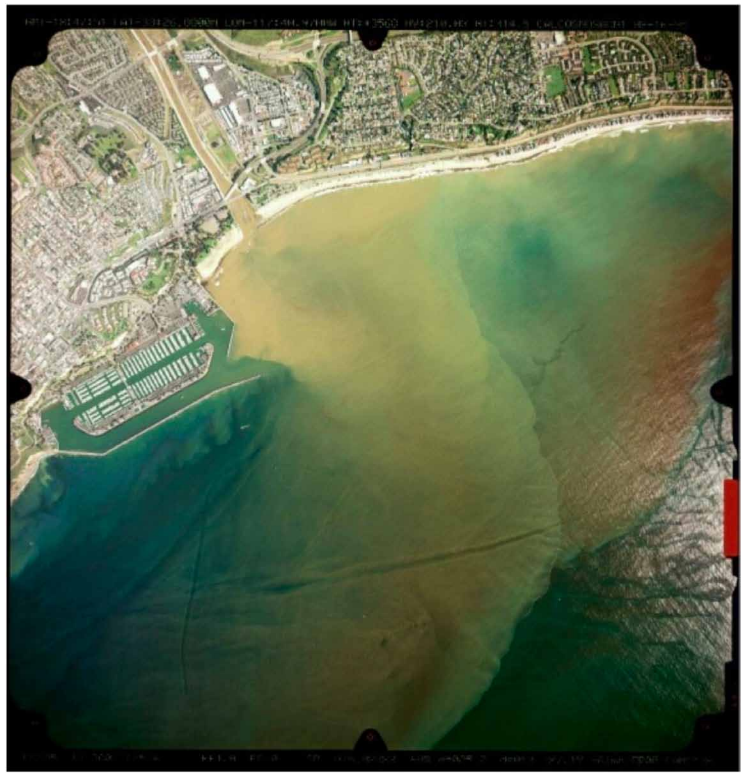


FIGURE 2. Soil erosion leading to surface water contamination (www.surfrider.org).

flammability, and temperature dependencies of all other properties. Solubility describes how well it mixes with water—highly soluble means it will completely dissolve into any water it contacts and will then move with that water. Volatility describes how readily the liquid can evaporate and enter the atmosphere. Low molecular weight organic compounds are usually very volatile. High molecular weight compounds typically have low volatilities, but can still evaporate over time. Inorganic compounds usually have very low to no volatility. Soil wettability describes how well the liquid spreads onto soil particles. If the liquid wets the soil it will tend to remain near the site of the spill, otherwise it could quickly flow away from the site. All of these properties are dependent on temperature, with higher temperatures making compounds more soluble, more volatile, and more wettable.

Examples

Process water, produced water, brine holding ponds, acid mine drainage, storm water retention basins, heavy metal contaminated waters, pipelines, wells, and containers moved along roadways and rail lines.

Solid Contaminants

The ability of solid releases to contaminate the environment depends on particulate sizes, water content, and reactivity. The main escape route is erosion, either by wind for smaller particulates or water. Smaller particulates are more easily transported by the atmosphere and tend to go farther once released. It is often best to wait for low wind speeds to work with fine solids outside. Other ways to reduce these releases are to spray water mist into the emission area to increase the size of the particles and to get them join together and settle by gravity. Wet solids do not tend to disperse by air, but may be eroded by water if allowed to come in

FIGURE 3. Soil surface contamination from rock pile leaching and drainage (deq.mt.gov).

contact with moving water or rain. These solids will be carried by the water and deposited along its flow path. Reactive solids may oxidize when exposed to air and form other products that may be released to the air or water. Prevention and controlled access are required to contain such releases.

Examples
Raw material gathering areas, storage areas, transfers, waste piles, tailings ponds, and exhaust and dust generated along transportation roadways and rail lines.

RELEASES

Contamination can occur at any location on a site, but are more likely to occur where transfers occur, at access points, and along transportation routes. Transfer refers to any point where the form of transport changes—such as loading into a truck or rail car, emptying a barrel, or feeding into equipment. Access points are areas where inputs and outputs enter/exit the site or where people interact with them. Transportation routes include roads, railway lines, and pipelines. Contamination may also occur at storage locations, though typically only due to unforeseen circumstances such as natural disasters. *Transfer points* allow releases because the transferred materials are exposed to the environment.

Gases

Gases will escape during transfer at any connection between systems. All pumps, valves, and fittings will leak to some extent. Wells can have significant leaks where it exits the ground and enters a pipeline, or within the well if the casing material fails due to corrosion or shifting of the ground. Good maintenance will minimize such releases. Active monitoring can catch leaks early.

Liquids

Liquids can escape through spills, evaporation or droplet entrainment. Spills of even a few drops can contaminate a soil, and if it is repeated (such as at a loading dock or liquid dispenser) can create large contamination areas. Spills can be controlled by providing a secondary barrier with capture system. This may involve paving the transfer zone and draining it to a liquid capture and storage basin. Such a system will capture large leaks, and hold contaminated rainwater for treatment. By capturing such releases only the storage area gets contaminated and cleanup is relatively simple. If the spill is not captured it will contaminate the nearby soil, surface water, and possibly the groundwater.

Evaporation occurs with all liquids but is especially important for volatile compounds (high vapor pressure at ambient conditions). These vapors can be released during transfers, when a storage tank is refilled, or from a poorly sealed storage container. Vapors can be captured during transfers or refilling with a vapor capture system. These systems may connect the gas phases between the re-filled and source tanks so the vapors leaving one will enter the liquid dispensing tank, however, these systems will have trouble if the temperatures between the two tanks are different. If this is the case a separate capture and adsorption or condensation system may be used to equalize pressure and facilitate the transfer.

Droplet entrainment happens whenever a liquid splashes. Small droplets break away from the main body of liquid and can be carried away in the air. It can be prevented by using submerged fill pipes. It can be controlled by venting the area into a droplet capture device, which requires the capture of all the air in the area and sending it through the device.

The control of acid mine drainage (AMD) should focus on water control. The ability of water to contact exposed mine rock creates the problem. Limiting this ability will reduce the amount formed. Developing systems to collect and channel process water, produced water, and rainwater away from the exposed areas will reduce the amount formed. Once formed the contaminated water should be diverted to containment systems. Additionally, groundwater pumping systems, subsurface drainage systems, or barriers can also limit the formation or release of AMD. Once formed it should be collected in a holding pond for evaporation or other treatment.

Particulates

Particulates will escape into the air, water, and/or soil wherever they are generated. Sources occur whenever solids are moved, abraded, transferred between containers, dumped, scraped, or driven over. Once released, they disperse and slowly deposit onto the ground or water downwind of the source. Reduction is possible by minimizing the number of transfers, minimizing the distance traveled, or using containment and capture at the source. Containment is used to eliminate the access of the particulates with ambient air—such as performing the transfer within a building. Even a three-sided structure can reduce the release of particulates. Capture collects all the air in the area and sends it through some type of collection device (fabric filter, cyclone, or settling chamber). The main goal here is to prevent an interaction with wind during the time required to capture the particulates and remove them—typically on the order of minutes to an hour depending on size and density.

FIGURE 4. Example of dust generated by traffic on unpaved road.

Unpaved roadways can be treated with produced water to control the release of dust from traffic. Piles of waste rock should be sloped in such a way to minimize uncontrolled run-off, to collect rainfall, and to control the velocity of the collected rainfall so it does not induce erosion of the waste rock.

Access points are similar to transfer points, although the main reason for a release is typically human error. Causes include inattention during a transfer, incorrect connections, poorly sealed fittings, and general carelessness. Good planning and a safety culture can minimize these problems. Good planning includes use of unique or color-coded fittings to make sure the proper connections are always made, proper maintenance of connection hardware, working in teams, and having active participation by all employees in spill notification and cleanup. As a minimum every person at the site should know what size spill requires notification and how to report a spill.

Transportation-related releases are typically caused by accidents or corrosion. Accidents can be reduced by careful planning of transportation routes—keep traffic on one way roads, minimize intersections, and have good marking of routes. Roads should not cross railway lines if possible, but if necessary have a minimum number of highly controlled crossings that are well marked. Most pipeline releases occur because of corrosion. It is difficult to know when a line will fail, but active maintenance and monitoring can find problems before a release occurs. Double wall pipe or secondary containment along the pipeline route is expensive but excellent for detecting leaks and minimizing cleanup costs.

FATE OF RELEASES

After release, each contaminant will spread out into the environment in different ways and will have different fates depending on its chemistry, the type of release, and the environment.
Chemistry Organic compounds will break down over time. Highly volatile compounds will react with sunlight and oxygen to form water, carbon dioxide, and other compounds such as acids if they contain chlorine or sulfur atoms. This breakdown may take hours, days, or in the case of methane, years. Less volatile materials will tend to accumulate in the soil near the area of release. They will typically be broken down biologically, although this may require years to be completed.

Inorganic compounds either are or will form oxides, carbonates, or sulfates once released into the environment. The important properties to consider for understanding their environmental fate are solubility (in water or organics) and overall reactivity. A water-soluble compound will be dissolved by whatever water it encounters (surface water or ground water) and be transported by it. An insoluble material will typically join with the soil or sediments and not be transported far from the release area. If the compound interacts with organics it may sorb onto a soil or be taken in by a plant or animal. Once taken in by an organism it may build up to very high levels in other organisms that consume the contaminated materials and organisms. Mercury is an example of a substance that accumulates in this way, and it can be found in fish at concentrations a million fold larger than the water in which the fish live. The more reactive a material is, the more quickly it will be oxidized and reach its final form. Less reactive species may have very complex interactions with the environment as it encounters oxidizing and reducing conditions. Examples are selenium and mercury, which can be released from sediments, soils, or water environments back into the atmosphere as they change from an organic state into an oxidized or reduced state.

Type of Release

Releases to the atmosphere tend to be quickly dispersed and spread out over a large area. Solids will slowly settle back to the ground (dry deposition) or be washed from the air by precipitation (wet deposition). Droplets may coalesce and be removed by wet or dry deposition (here wet means combined with water). Gases are much slower to remove. Reactive materials tend to oxidize in the atmosphere. Gases that contain sulfur or chlorine will form acids (sulfuric and hydrochloric, respectively) leading to acid rain problems. Fully oxidized materials will accumulate in the atmosphere and form part of a cycle whereby it is transferred to the ground over time and can be re-released. Water has a residence time of a few days, after which it precipitates and enters the hydrological cycle. Carbon dioxide (CO_2) has multiple cycles. The fastest (1–5 years) is transfer between the air and ground or water surface where it is taken in by plants only to be released back into the atmosphere when the plants die. Next (100–5,000 years) is transfer within soils and the ocean. Finally, there is deposition in ocean sediments (106 or more years). Because this last cycle is small and slow to remove CO_2, it is building up in the earth's atmosphere. This causes an otherwise harmless and inert compound to be the most important unsolved global pollution problem. Other reactions may cause the formation of solids or liquids, which are then removed by wet or dry deposition, as discussed above.

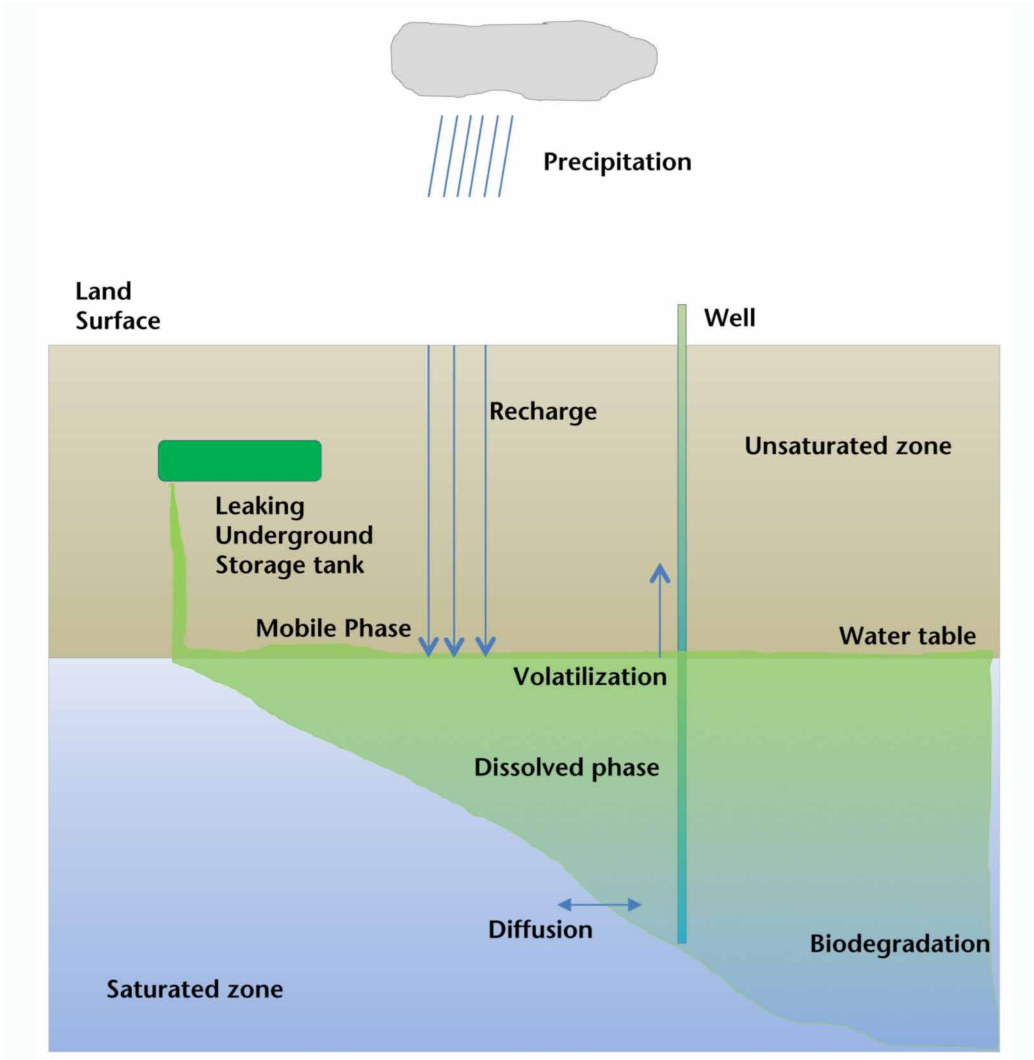
Releases to surface water can carry a contaminant many miles in a short time. During this transportation, the substance will contaminate water, sediments, plant and animal life, and can pose a danger to humans. These effects can be minimized by controlling the movement of a spill or release in order to reduce the amount that enters the water body. Control is by physical barriers such as berms, collection ponds, and controlled drainage with collection basins. Monitoring is relatively easy either with visual inspection or grab-samples and a relatively quick and simple lab analysis. This type of contamination can be readily observed and even detected automatically with appropriate equipment.

Releases to ground water are difficult to notice or monitor. Groundwater is water that exists within soils and broken rocks underneath the ground. The main source of groundwater is rain seeping into the soil—a process called infiltration. Aquifers are sections of soil and/or rock that hold sufficient groundwater that can be taken for use. Water can be removed from an aquifer with a well and pump. The aquifer can be used as a source of water or for waste disposal (very deep aquifers only).

Once a contaminant is released onto the ground it will seep down and reach the groundwater. At that point it can start to move laterally with the groundwater flow. Some materials will float and be distributed along the surface of the groundwater table, which can fluctuate over time, contaminating all the soil in the region between the saturated and unsaturated zones. Some materials will sink and collect at the bottom of the aquifer and then disperse downhill and in the direction of flow. Other materials will dissolve into the groundwater and be carried along by it, contaminating all the aquifer material along the way. It may only be first noticed when it enters a well or discharges to surface water.

Groundwater flow is much slower than surface water. Speeds may range from a few feet per hour to less than a mile per year. As the contamination moves it disperses, spreading out and decreasing in concentration. The contamination can be described as an underground plume, containing higher concentrations along the center and lower concentrations the farther from the center and from the source. The longer the material is in the aquifer, the larger the volume of the plume. A complication is that it is nearly impossible to know the structure of the aquifer so predicting where the plume will travel is extremely difficult. It is also very dif-

FIGURE 5. Diagram showing the source and fate of a leaking underground storage tank as it contaminates nearby groundwater with gasoline (USGS http://pubs.usgs.gov/fs/FS-019-98/).



ficult to measure concentrations underground, which requires the drilling of sampling wells. Determining where to drill a well is also very complicated, and wells that miss the plume can happen. Also, sampling wells can actually speed up and redirect a plume unless great caution is used during well installation.

Cleaning up groundwater is very difficult. The process must remove the contaminant from the water and from the soil. Some technologies to accomplish this are bioremediation, soil vapor extraction (SVE), and pump-and-treat. Bioremediation involves using bacteria to clean up the contamination by "eating" it. Usually nutrients are pumped down into the contaminated area. The nutrients help bacteria, which are already in the groundwater, to grow and destroy the contamination. In SVE, air is pulled through the ground in order to pull volatile contaminants out of the groundwater. This method also increases air movement underground so that the helpful bacteria in the ground can "breath" better and destroy more contaminants. The air that is pulled out of the ground then needs to be treated. Groundwater can also be cleaned by pumping it to the surface and cleaning it above ground. The clean water is then pumped back into the ground. This is a problem sometimes, as there might not be any space to put it while it is being cleaned. Another issue is that while the water is now clean, the removed contaminant still needs to be disposed of safely somewhere. Each of these processes can require years to achieve the desired level of remediation. The best way to deal with groundwater contamination is not to contaminate it in the first place!

Releases to the ground will mix with ground material (soil, rock, or pavement). It may mix with rainwater and seep into the groundwater (see above section). It can also be washed away into nearby surface waters or it can stick to the nearby ground. The first cases have already been discussed. Contaminated ground must be treated to remove the contamination. If the contamination is slight and not particularly noxious, the ground can be treated to reduce the transport of the substance: increase the pH to above 6.5; draining wet soils; applying phosphate; or planting certain crops which accumulate the material in their roots, stems or leaves (with subsequent harvesting to remove the contaminant). For more extreme contamination, the treatment will include removing the soil and then either heating it to destroy the contaminant; adding solidifying agents to reduce the ability of water to leach out the contaminant; or washing the soil to leach out the contaminant. In each case the treated material and collected waste must be properly disposed of.

Environment
Knowledge of the local and regional area around a site can help the designer minimize the impact of releases when they happen, and increase the chances that monitoring will detect a spill as soon as possible.

Elevation
In general, spills flow downhill. This is true for gases, liquids, and solids. Monitoring devices should be located in areas where releases are likely to move toward. Physical barriers, containment structures, and alert systems should be added before a problem occurs. Knowledge of local elevation and what objects exist downhill (on-site and off-site) is essential for planning. If people are downhill/downwind, the level of protection must be greater and evacuation plans must be considered.

Surface Water
All surface water should be periodically monitored. If possible, barriers should be erected between areas where releases may occur and access to the surface water. A good design will make it nearly impossible for a release to enter surface water under any conditions (including tornado, hurricane, heavy rain, major flood, or fire and explosion).

Storm Water
Accidents are more likely during storms. Controlling where storm water enters and leaves a site is essential for controlling releases. Storm water retention ponds can store moderate amounts of water before it is released from a site. The basin can be designed to treat small levels of contamination through biological processes. The exit point of the storm water should slow flow to allow solids to settle out and allow time for biological activity to start destroying any contaminants. Ideas to reduce the impact from storm water include: designing an exit that must first percolate through a bed of wood chips (enhances biological destruction); and planting certain species (willow trees, birch trees, and cattails for example) within the retention basin to hold water and adsorb some contaminants.

Ground Water

Releases that seep into groundwater are the most difficult and costly cleanup projects. It is very important to understand where the groundwater is at your site (depth); where it is going (direction); how fast it is moving (velocity and flow rate); and how it changes over time. With this knowledge it is possible to catch releases as soon as possible and begin cleanup in an efficient and timely manner. Monitoring groundwater levels, flows, and directions requires the construction and use of monitoring wells. Wells can be used to observe water height and to collect water samples. Water height (or pressure) is used to deduce both the flow rate and direction of flow. These may vary over time, so frequent analysis (monthly) is required. Collected water samples can be monitored for contaminants. It may be useful to have wells located upstream and downstream to show if a particular contaminant is entering your site from some other location. However, the cost of these wells can be large and they are not guaranteed to observe a release.

Another issue with monitoring wells is that they can provide very quick access to the aquifer for a surface spill. As such they need to be designed to protect the groundwater. They should have attached caps and a raised entrance. The attached cap cannot get misplaced or lost. A physical barrier will prevent a release from entering the well if somehow the cap is not securely replaced.

Neighbors

All sites have neighbors. A good plan will work with them to reduce release threats from their site to yours and your site to theirs. A regional plan may be less expensive and easier to monitor and maintain than individual local plans. A larger scale focus can be used to minimize the harm and cost. However, not all neighbors are easy to work with.

TIME

The potential for a release will vary with different phases of a project—site preparation, site use, expansion, and closure.

Site preparation has the potential for releases of natural and construction materials. Typically, soil is released through erosion. There are many ways to reduce this, including minimizing the foot print of the activity, active barriers to prevent the release of such materials, and passive barriers to prevent erosion. Footprint can be minimized by careful consideration of the site and thoughtful planning of construction activities. Not all sites need to be clear-cut and sculpted. Leaving some existing vegetation will decrease erosion, provide wind and sun barriers, as well as potentially increase the value of a site. Active barriers are used to capture releases before they exit the site. A temporary water retention basin will slow the flow of storm water and allow eroded soil to settle from the water. A passive barrier prevents the erosion from happening. It can include a line of trees or other barrier to slow wind or placing a covering over exposed soil during a storm event.

Site use includes startup, operations, and maintenance shut down. All of these have the potential to release the raw materials and products from the operation. The project will spend the most time in these modes and more types of contaminants can potentially be released. Vigilance is most difficult to maintain during operations as people fall into routines and awareness decreases. Standard operating procedures that include monitoring combined with active and frequent reminders can help.

Expansion or construction projects on the site can have releases as described in both the above paragraphs. The increase in traffic and access by people with less experience at the site will increase the chances of an accident. Enhanced monitoring and protection in and around the work area will help minimize releases during this transition time. People are more aware of their surrounding during times of change, you can use this to encourage all people on the site to actively monitor the area and to discuss any potential problems they observe with project team leaders.

Closure occurs at the end of the project. It is also when many problems are first found, because no one reported them at the time they occurred or it wasn't monitored and escaped notice. This is the most expensive time to find out, as the contaminant will have had the most time to disperse into the ground and water. There is little to do at this point except start a clean-up program. Let this be a warning.

STANDARDS AND REGULATIONS

It is incumbent on every operation to become familiar with all laws and regulations concerning the use and release of materials and energy at your specific location. There may be local, regional, national, and international rules concerning what actions you must perform (floating roof storage containers, secondary containment, water and air sampling programs). These are specific to your location and industry. In general they are designed and informed by what has worked in the past to best preserve the environment and is workable by most participants in an industry. A successful long-term plan will go beyond the required minimum activities with careful planning. It is also very useful to develop a culture of safety, prevention, and vigilance—none of which can be regulated—but demonstrates your intentions to be a good neighbor and citizen.

CONCLUSION

The point of this article was to increase your awareness of what contaminants are; how they may be released; where they end up after release; and to provide some general ideas on how to minimize the likelihood of a release and to minimize the impacts from a release. In summary, a well-maintained site with an active, well-thought-out monitoring program and people that are concerned with safety will have much lower risks for having a release and those releases will be smaller and easier to remediate.

GENERAL U.S. REFERENCES FOR ADDITIONAL INFORMATION

EPA Oil and Gas Sector—http://www.epa.gov/lawsregs/sectors/oilandgas.html
EPA Sustainable Practices—http://www2.epa.gov/science-and-technology/sustainable-practices
EPA Pollution Prevention—http://www.epa.gov/p2/
EPA Mining Sector—http://www.epa.gov/lawsregs/sectors/mining.html
DOE Energy Information Administration—http://www.eia.gov/
USGS Energy and Minerals—http://www.usgs.gov/energy_minerals/
USGS Toxic Substances Hydrology—http://toxics.usgs.gov/