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Soil Pollution and Soil Remediation Techniques

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***Abstract:** In a general sense, soil pollution definition is the presence of toxic chemicals (pollutants or contaminants) in soil in high enough concentrations to be of risk to human health and/or ecosystem. Additionally, even when the levels of contaminants in soil are not of risk, soil pollution may occur simply due to the fact that the levels of the contaminants in soil exceed the levels that are naturally present in soil (in the case of contaminants which occur naturally in soil).Soil pollutants include a large variety of contaminants or chemicals (organic and inorganic), which could be both naturally-occurring in soil and man-made. In both cases, the main soil pollution causes are the human activities (i.e., the accumulation of those chemicals in soil at levels of health risk is due to human activities such as accidental leaks and spills, dumping, manufacturing processes, etc.) 125 major contaminated sites across the country 175 million hectare (out of 329 million ha) are considered degraded 40 % of chemical fertilizers leached into soil 14 States are affected by Fluoride contamination • > 65 per cent of India's villages are exposed to residual pesticides risk Heavy metals beyond permissible limits affecting GW of 40 districts from 13 states. This is possible due to the complex soil environment involving the presence of other chemicals and natural conditions which may interact with the released pollutants various causes for soil pollution are detailed below. Of these causes, sites are important causes of soil pollution in urban area due to their almost ubiquitous nature. In general, any chemical handled at construction sites may pollute the soil. However, the higher risk come from those chemicals that may travel easier through air (as fine particulate matter) and which are resistant to degradation and bio accumulate in living organisms. Enhancing functional capacities of various tiers Strategic interventions in critical areas Innovating funding mechanisms and PPP Building synergies for expediting decision making Community mobilization: awareness and education. While in situ remediation is more cost effective, the thoroughness of this method is less effective than the ex situ remediation. Ex situ remediation is less cost effective, but is a more thorough remediation method. This paper will evaluate the benefits and costs of each technique*

***Keywords:** Geotechnical Techniques, Drains, Grouting, Bioremediation, ex situ remediation, In Situ Remediation, Landfarming, Bioventing, Biosparging, Bioslurping, Phytoremedia.*

I. INTRODUCTION

Soil pollution has been a major concern for environmentalists all around the world. This article will tell you all about the need of taking necessary steps to bring antend to the adverse affects of soil pollution! Have a look Land pollution is the addition of undesirable matter to the land that damage the terrestrial organisms, reduce the uses of the land by man for agricultural, residential, recreational or other purposes or increase the risk of health hazards to man.…

Leakages from sanitary sewage.

Causes

Acid rains, when fumes released from industries get mixed with rains. Fuel leakages from automobiles, that get washed away due to rain and seep into the nearby soil. Unhealthy waste management techniques, which are characterized by release of sewage into the large dumping grounds and nearby streams or rivers. Industrial wastes, such as harmful gases and chemicals, agricultural pesticide, fertilizers and insecticides are the most important causes of soil pollution. Ignorance towards soil management and related systems. Unfavorable and harmful irrigation practices. Improper septic system and management and maintenance of the same.

Effects of Soil Pollution:

Fig: Effect of soil pollution

The effects of pollution on soil are quite alarming and can cause huge disturbances in the ecological balance and health of living creatures on earth. Some of the most serious soil pollution effects are mentioned below. Decrease in soil fertility and therefore decrease in the soil yield. Definitely, how can one expect a contaminated soil to produce healthy crops? Loss of soil and natural nutrients present in it. Plants also would not thrive in such a soil, which would further result in soil erosion. Disturbance in the balance of flora and fauna residing in the soil. Increase in salinity of the soil, which therefore makes it unfit for vegetation, thus making it useless and barren. Generally crops cannot grow and flourish in a polluted soil. Yet if some crops manage to grow, then those would be poisonous enough to cause serious health problems in people consuming them.

Causes of soil pollution:

Soil pollution is a result of many activities and experiments done by mankind and some of the leading soil pollution causes are discussed below. Industrial wastes, such as harmful gases and chemicals, agricultural pesticide, fertilizers and insecticides are the most important causes of soil pollution. Ignorance towards soil management and related systems.

- Unfavorable and harmful irrigation practices.
- Improper septic system and management and maintenance of the same.
- Leakages from sanitary sewage.
- Acid rains, when fumes released from industries get mixed with rains.
- Fuel leakages from automobiles, that get washed away due to rain and seep into the nearby soil.
- Unhealthy waste management techniques, which are characterized by release of sewage into the large dumping grounds and nearby streams or rivers.

Fig: Causes of soil pollution

Solutions for Soil Pollution

Soil pollution has many sources, from agriculture to industry to human activity. Polluted soils affect harm life and, in turn, wildlife. Depending upon the polluting agent, pollutants can persist in the environment. Solutions, therefore, involve not just removing a source of pollution but also cleaning up and restoring the polluted area. Adding to the complexity of soil pollution is nonpoint source pollution (NSP), which enters the environment through runoff. Take any action at your disposal to reduce soil pollution, as you may not always find a clearly defined source.

Reduce Waste

Consider the amount of needlessly generated waste. According to the Clean Air Council, almost one-third of the waste in the U.S. comes from packaging, with an additional five million tons generated during the holiday season. Chemicals used in paper manufacturing can end up in the soil. Choose wisely when shopping; avoid purchasing products with excessive packaging. Reuse holiday wrap, or cut down on the amount you use.

Agriculture Best Practices

The EPA has identified agricultural runoff as the primary source of water pollution. Runoff contains pesticides, fertilizers, and agricultural waste that can have harmful effects on soils. Excessive amounts of phosphates, phosphorus and nitrogen found in fertilizers can cause fish and plant kill, resulting in contaminated soils. Use organic herbicides when gardening, or none at all. Plant native plants, which thrive in local conditions, often making pesticide use unnecessary

Wetland Restoration

Help restore polluted wetlands. A single acre of wetlands can hold more than of one and a half million gallons of water, which runoff can taint, eventually leading to soil pollution. Work to restore wetlands and reduce NSP. Support local conservation efforts by donating to or volunteering with organizations such as The Nature Conservancy that purchase land for restoration.

Reduction of Acid Rain

Sulfur dioxide emissions can cause acid rain and forest destruction. Fortunately, the introduction of scrubbers on smokestacks of coal-burning power plants has produced some progress in this arena. The U.S. Environmental Protection Agency (EPA) reports a 71 percent decrease in sulfur dioxide concentrations from 1980 to 2008. Help solve the problem by contacting your legislators and asking them to encourage development of alternative fuel sources..

Soil Improvement

Methods of soil improvement:

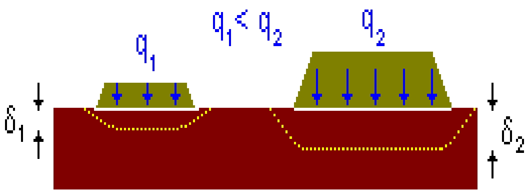
- Removal and replacement
- Precompression
- Vertical drains
- In-situ densification
- Grouting
- Stabilization using admixtures
- Reinforcement

Removal and replacement:

- One of oldest and simplest methods is simply to remove and replace the soil
- Soils that will have to be replaced include contaminated soils or organic soils
- Method is usually practical only above the groundwater table

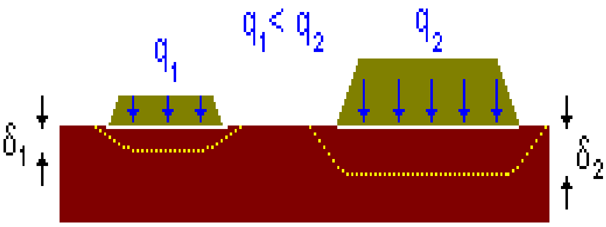
Precompression:

- Simply place a surcharge fill on top of the soil that requires consolidation
- Once sufficient consolidation has taken place, the fill can be removed and construction takes place
- Surcharge fills are typically 10-25 feet thick and generally produces settlement of 1 to 3 feet.
- Most effective in clay soil



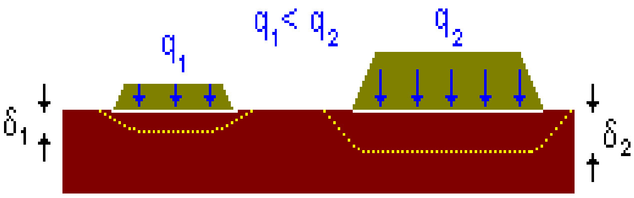
Advantages of Precompression

- Requires only conventional earthmoving equipment
- Any grading contractor can perform the work
- Long track record of success



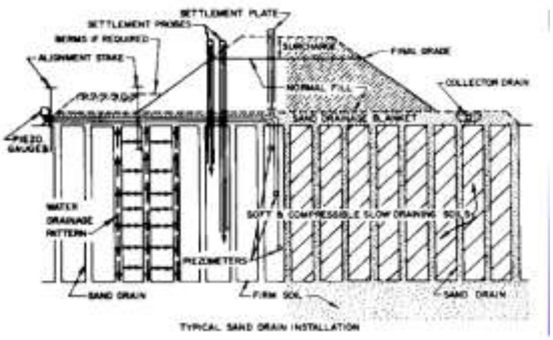
Disadvantages of Precompression

- Surcharge fill must extend horizontally at least 10 m beyond the perimeter of the planned construction, which may not be possible at confined sites
- Transport of large quantities of soil required
- Surcharge must remain in place for months or years, thus delaying construction



Vertical Drains

- Vertical drains are installed under a surcharge load to accelerate the drainage of impervious soils and thus speed up consolidation
- These drains provide a shorter path for the water to flow through to get away from the soil
- Time to drain clay layers can be reduced from years to a couple of months



Wick Drains

- Geosynthetics used as a substitute to sand columns
- Installed by being pushed or vibrated into the ground
- Most are about 100 mm wide and 5 mm thick

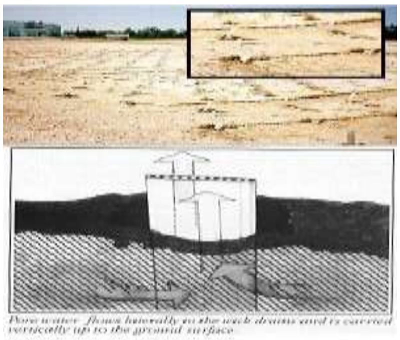


Fig: Wick Drains

Typical installation of wick drains

- Typically spaced 3 m on centers

Prefabricated Drains Available in US

- Alidrain
- Aliwick
- Ameridrain
- Colbond Drain

Fig: Drains

In-situ densification

- Most effective in sands
- Methods used in conventional earthwork are only effective to about 2 m below the surface
- In-situ methods like dynamic deep compaction are for soils deeper than can be compacted from the surface

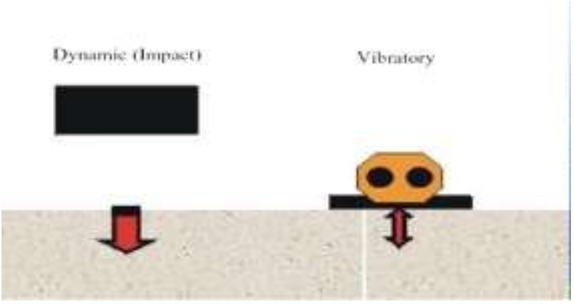


Fig: insitu

Vibroflotation

- Probe includes the vibrator mechanism and water jets
- Probe is lowered into the ground using a crane
- Vibratory eccentric force induces densification and water jets assist in insertion and extraction
- Vibratory probe compaction is effective if silt content is less than 12-15% and clay is less than 3%
- Probes inserted in grid pattern at a spacing of 1.5 to 3 m

Fig: vibrofloatation

Vibro-replacement stone columns:

- Vibro-Replacement extends the range of soils that can be improved by vibratory techniques to include cohesive soils. Reinforcement of the soil with compacted granular columns or "stone columns" is accomplished by the top-feed method.

Dynamic compaction:

- Uses a special crane to lift 5-30 tons to heights of 40 to 100 feet then drop these weights onto the ground
- Cost effective method of densifying loose sands and silty soils up to 15 to 30 feet deep

Fig: Dynamic Compaction

Grouting

- Defined as the injection of a special liquid or slurry material called grout into the ground for the purpose of improving the soil or rock

- Types of grouts

  - Cementitious grouts
  - Chemical grouts

Grouting methods

- **Intrusion grouting**

  - Consists of filling joints or fractures with grout
  - Primary benefit is reduction in hydraulic conductivity
  - Used to prepare foundation and abutments for dams
  - Usually done using cementitious grouts

- **Permeation grouting**

  - Injection of thin grouts into the soil
  - Once the soil cures, becomes a solid mass
  - Done using chemical grouts
  - Used for creating groundwater barriers or preparing ground before tunneling

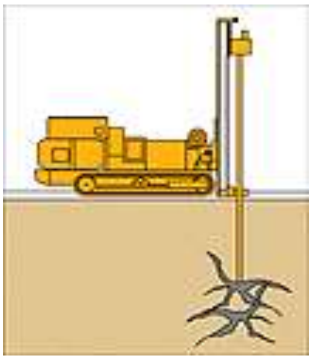


Fig: permeation Grouting

- **Compaction grouting**

  - When low-slump compaction grout is injected into granular soils, grout bulbs are formed that displace and densify the surrounding loose soils.
  - Used to repair structures that have excessive settlement

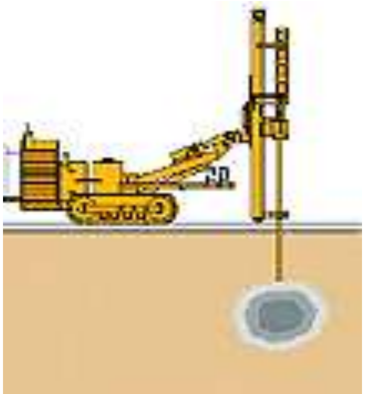


Fig: compaction grouting

- **Jet grouting:**
  - Developed in Japan
  - Uses a special pipe with horizontal jets that inject grout into the ground at high pressures
  - Jet grouting is an erosion/replacement system that creates an engineered, in situ soil/cement product known as Soilcrete^{sm}. Effective across the widest range of soil types, and capable of being performed around subsurface obstructions and in confined spaces, jet grouting is a versatile and valuable tool for soft soil stabilization, underpinning, and excavation support and groundwater control.

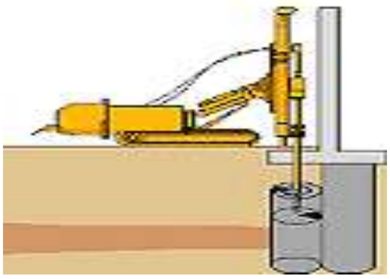


Fig: Jet Grouting

Stabilization using admixtures

Environmental Techniques:

Bioremediation is defined as "The use of biological mechanisms to destroy, transform, or immobilize environmental contaminants in order to protect potential sensitive receptors." (Bioremediation Discussion Group, 2006). Ex situ remediation techniques involve removing the soil from the subsurface to treat it. In situ remediation techniques involve leaving the soil in its original place and bringing the biological mechanisms to the soil. In the past, thermal, chemical, and physical treatment methods have failed to eliminate the pollution problem because those methods only shift the pollution to a new phase such as air pollution. Bioremediation technology, which leads to degradation of pollutants, may be a lucrative and environmentally beneficial alternative that could produce economic profit. Ex situ and in situ techniques each have specific benefits and costs.

EX SITU REMEDIATION TECHNIQUES

Ex situ remediation includes techniques such as landfarming, biopiling, and processing by bioreactors along with thermal, chemical, and physical processes. Ex situ remediation is a more thorough remediation technique, but due to the costs associated not only with the remediation processes, but also will the excavation and transportation of the soil, many people are looking towards in situ remediation techniques.

Ex situ thermal processes involve the transfer of pollutants from the soil to a gas phase. The pollutants are released by vaporization and the burned at high temperatures. Ex situ thermal remediation is completed in 3 steps: soil conditioning, thermal treatment, and exhaust gas purification. Soil condition is a process in which broken into small grains and sieved in preparation for thermal treatment. Thermal treatment heats the soil in order to transfer volatile pollutants to a gas phase. Heating is done by using a sintering strand, fluid bed, or rotary kiln plants. The soil is usually heated to a low temperature range of 350-550^{o}C. Combustion of the gases occurs over the top of the soil, but the volatile gases are not destroyed. The gases are then burned in an after-burner chamber at approximately 1200^{o}C and dioxins are destroyed.

Ex situ thermal remediation processes are ideal for use when removing petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAH), benzene, toluene, ethylbenzene, xylenes (BTEX), phenolic compounds, cyanides, and chlorinated compounds like polychlorinated biphenyls (PCB), pentchlorphenol (PCP), chlorinated hydrocarbons, chlorinated pesticides, polychlorinated dibenzodioxins (PCDD), and polychlorinated dibenzofurans (PCDF).

The ex situ chemical/physical remediation process known as soil scrubbing uses mechanical energy to separate the pollutants from the soil. The soil is crushed and then separated via sieving. This ensures that the soil sample is homogeneous. The soil is then dispersed in liquid. Water, which is sometimes enhanced with an additive, is used to dissolve the pollutant. The additives are used to overcome the bonding forces between the pollutants and the soil particles. The soil is then separated into two categories: low density and high-density solids. Highly polluted fine particles are then separated out and dewatered. The particles are then rinsed with uncontaminated water. The wastewater and exhaust air are then purified. Soil scrubbing is most effective when removing BTEX, TPH, PAH, PCB, heavy metals, and dioxins.

Ex situ biological processes include: composting, land farming, bio piling and the use of bioreactors. Composting consists of excavating the soil and then mixing organics such as wood, hay, manure, and vegetative waste with the contaminated soil. The organics are chosen based on their ability to provide the proper porosity and carbon and nitrogen balances to aid in the breakdown of contaminants. Maintaining thermopile temperatures 54 to 65oC is an important part of composting. In most cases, the indigenous microorganisms maintain this temperature while degrading the contaminant. Composting is most effective when removing PAH, TNT, and RDX.

Land farming is a process in which the soil is excavated and mechanically separated via sieving. The polluted soil is then place in layers no more than 0.4 meters thick. A synthetic, concrete, or clay membrane is then used to cover the contaminated soil layer. Oxygen is added and mixing occurs via ploughing, harrowing, or milling. Nutrients and moisture may also be added to aid the remediation process. The pH of the soil is also regulated (keeping it near 7.0) using crushed limestone or agricultural lime. Land farming is most successful in removing PAH and PCP. Figure 1 illustrates the land farming technique.

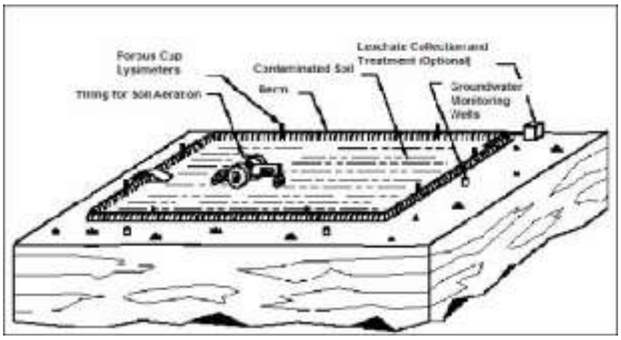


Figure 1: Landfarming Technique

Biopiling is an in situ process that is also known as the heap technique. The first step in the biopiling process is to perform laboratory tests that will determine the biological degradation capabilities of the soil sample. The next step involves the mechanical separation of the soil, which will homogenize the sample and remove any disruptive material such as plastics, metals, and stones. The stones will then be crushed into smaller pieces and then depending on the degree of contamination will either be added to a pile or sent out for reuse. The soil is then homogenized, meaning that the pollution concentration is averaged out across the entire soil sample. Homogenization allows for bio piling to be more effective.

Once the soil is piled, nutrients, microbes, oxygen, and substrate are added to start the biological degradation of the contaminants. The results of the initial laboratory tests indicate to the operators which substrates such as bark, lime, or composts needs to be added to the soil. Nutrients such as mineral fertilizers may also be added. Additionally, microorganisms such as fungi, bacteria, or enzymes could be added.

Static piles are usually in the form of pyramids or trapezoids. Their heights vary between 0.8 and 2m depending on the type of aeration used (either passive or active). Dynamic biopiles are consistently plowed and turned to maximize their exposure to increase the bioavailability of the contaminants by constantly exposing them to oxygen, water, nutrients, and microbes. No matter which types of heaps are used, the area below each heap must be covered in asphalt or concrete to prevent the seepage of contaminants and the area above the heaps must be covered in order to control temperature and moisture content conditions. A diagram for the heap techniques is shown in Figure 2. across the entire soil sample. Homogenization allows for biopiling to be more effective.

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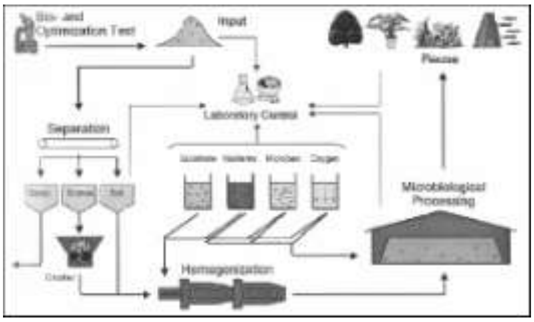


Figure 2: Heap Technique Diagram.

Biopiling is most effective in treating pollutants such as BTEX, phenols, PAHs with up to 4 aromatic rings, and explosives such as TNT and RDX. Each pollutant requires slight modifications to the basic technique. A specific modification is applied to volatile hydrocarbons. These volatile gases must be removed with a soil vapor extraction system and treatment biofilters and activated carbon filters. The heap technique is very economically efficient due to its low installation cost. The cost of operation is also low due to the low cost technology used in the treatment. More and more treatment plants are being built, which reduces the transportation costs, but government regulation is becoming stricter making it more expensive to transport and eventually dispose of the soil.

Bioreactors treat contaminated soils in both solid and liquid (slurry) phases. The solid phase treatment process mechanically decomposes the soil by attrition and mixing in a closed container. The objective of the mixing is to guarantee that the pollutants, water, air, nutrients, and microorganisms are in permanent contact.

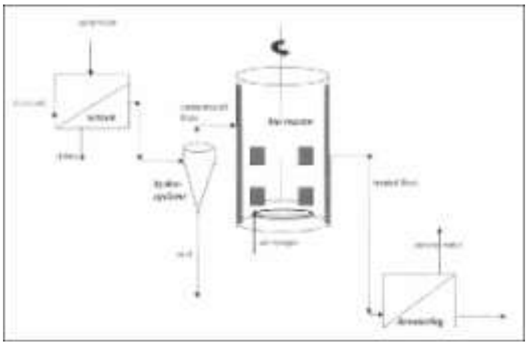


Figure 3: Typical Slurry Bioreactor.

An acid or alkalinity may also be added to control the pH. In fixed bed reactors, composts is added and significantly increases the degradation rate. In rotating drum reactors, the drum has a screw like mechanism in the middle of it that rotates to mix and transport the soil. The liquid phase treatment process uses suspension bioreactors and treats soils as slurry. The slurry feed enters the system and is rinsed through a vibrating screen to remove debris. Sand is then removed using a sieve or hydrocyclone. If a hydro cyclone is used to remove the sand, the sand falls to the bottom of the cyclone and the fines remain on top. The fines are then treated in a bioreactor. After the treatment, the slurry must be dewatered and the water is then treated with standard wastewater techniques. A typical slurry bioreactor setup is illustrated in Figure 3.

A major advantage of ex situ bioremediation processes is that most of the decontaminated soil can be reused. Due to the ex situ techniques used to decontaminate the soil, much of the soil cannot be used as filling or agricultural material. The soil can, however, be used for landscaping purposes. If soils are treated with thermal processes or a wet scrubber they may be reused as filling material. A key factor in determining the applicability of soil reuse is the toxicological assessment. Bioassays must be conducted in order to determine the impacts the soil will have on the surrounding area

IN SITU REMEDIATION TECHNIQUES

In situ remediation includes techniques such as bioventing, biosparging, bioslurping and phytoremediation along with physical, chemical, and thermal processes. In situ remediation is less costly due to the lack of excavation and transportation costs, but these remediation techniques are less controllable and less effective. Figure 4 illustrates the localization of selected in situ bioremediation processes.

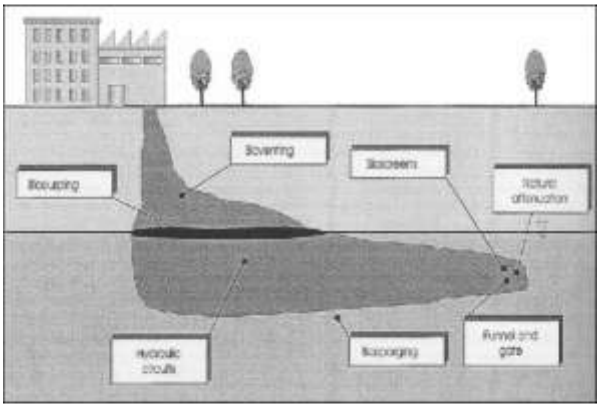


Figure 4: Localization of different microbial in situ technologies

In situ thermal processes are still in the developmental phase. The process involves injecting a steam-air mixture at 60-100oC into the soil. In order to avoid the transport of pollutants to the groundwater, the steam-air mixture must stay in that temperature range. After the injection, volatile and semi-volatile compounds transport from the soil to the gas phase. The gases are then removed from the subsurface using a soil vapor extraction system and then treated at the surface. In situ thermal remediation is limited for use in only certain soil types, namely homogeneous soils with high permeability and low organic content. In situ thermal processes are only appropriate for removing pollutants, which can be stripped in the lower temperature range

In situ chemical/physical processes are sometimes referred to as pump and treat processes. The pump and treat process pumps water into the subsurface in order to draw out the contaminants. Surfactants are sometimes added to the water to increase the solubility of the pollutants. The water is then treated with standard wastewater treatment techniques. The pump and treat process is extremely limited by the permeability of the soil. Chemical oxidation is also employed to destroy contaminants such as PAHs and trichloroethylene (TCE). (Chemicals such as ozone, permanganate, and peroxide have all been injected into the soil and used to accelerate the destruction of toxic organic compounds.

Another in situ chemical/physical process used is soil vapor extraction. Vacuum blowers are used to extract volatile pollutants for the soil through perforated pipes. The volatile pollutants are then treated at the site using activated carbon filters or compost filters. The effectiveness of this technique is dependent on soil characteristics such as moisture content, temperature, and permeability. A high percentage of fine soil or a high degree of saturation can also hinder the effectiveness of soil vapour extraction. Complete decontamination of the soil is rarely achieved with this technique.

Bio venting is the only in situ bioremediation technique that allows for the treatment of unsaturated soil. Bio venting is not effective if the water table is within several feet of the surface. uses a vacuum enhanced soil vapour extraction system. Due to the pressure gradient in the soil, atmospheric oxygen flows into the subsurface. This oxygen starts an aerobic contaminant decomposition process. In many cases it is necessary to add nitrogen salts as an additive by sprinkling a nutrient solution on top of the soil or by injecting them into the soil above the contaminated soil zone.

Sufficient airflow is very important in the design of a bio venting system. The geometry of the exfiltration wells and the need for active or passive air injections are two particular design concerns. If a high concentration of pollutants exists, clogging of the soil pores may occur. In this case, pulsed soil vapour extraction is needed. Low permeability will also hinder Bio venting. If the soil vapours are volatile, they must be treated at the surface with an activated carbon filter or a bio filter. Bio venting is effective in removing petroleum hydrocarbons, aromatic hydrocarbons, and non-volatile hydraulic oils. Low temperatures hinder the effectiveness of bio venting. Bio venting is normally only effect in areas with high temperatures Figure 5 illustrates a typical bio venting system.

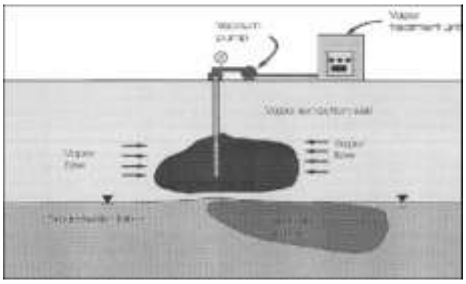
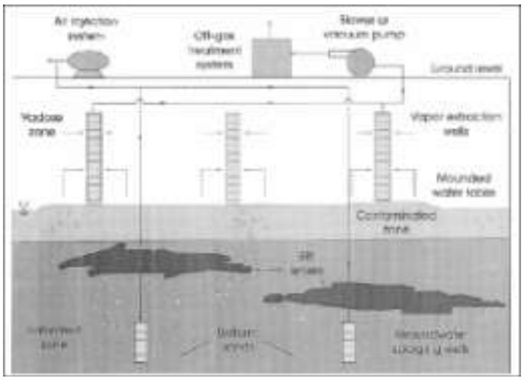


Figure 5: Illustration of bioventing system.

Biosparging is the injection of atmospheric air into the aquifer. It is used in both saturated and unsaturated soil zones. The technique was developed to reduce the consumption of energy. The injection of air into the aquifer results in small channels for the air to move to the unsaturated soil zone. In order to form the necessary numerous branches in these channels, the air must be pulsed into these soil. Biosparging results in volatile contaminants being transported to the unsaturated zone, therefore soil vapor extraction is usually used to extract the volatile vapours and then treat them at the surface.

In order for Biosparging to be effective, the sparge points must be installed below the contamination zone because air always flows upward. The up flow of air will form an influence cone. The degree of branching and the angle of the cone are determined by the amount of air pressure during the injection. The degree of influence for each sparge point is determined by a pilot test. Monitoring wells are installed around the point and then the groundwater level and dissolved oxygen content are measured to determine the zone of influence for the sparge point. In order to effectively remove contaminants from the soil using biosparging, the soil should be relatively homogeneous throughout the contamination zone. (Held and Dörr, 2000). Figure 6 illustrates a biosparging system.



A case study performed in the Damodar Valley in Eastern India showed that biosparging was effective at removing 75% of contaminants present within a one year time period. The first results were obtained in the field, but these results were enumerated using a laboratory tests and computer programs. The results from the study were used to set the optimum conditions for remediation including: proper moisture content, pH, temperature, nutrients, and carbon sources. The field tests used six separate tests sites. Different parameters were tested in each site in order to investigate the optimum conditions.

Bio slurping is a unique in situ treatment technique in that it also treats free product phases floating on top of the groundwater. This technique applies a vacuum to extract, soil vapour, water, and free product from the subsurface. Each of those products is separated and then treated. This technique is cost effective because only a small amount of groundwater and soil vapour are pumped at a time, therefore the treatment plant used to treat the vapour and free product can be small.

Bio venting, biosparging, and bio slurping are only effective if the soil being treated is homogeneous. If a remediation area has non-homogeneous soil, it may be best to consider passive treatment techniques. Passive treatment involves applying treatment techniques at the ends of contamination plumes. There are 4 different types of passive treatment: activated zones, bio screens, reactive walls, and reactive trenches

Activated zone consists of a line of narrow wells. The wells alternate pumping and rein filtration of groundwater in closed, directly linked loops. Nutrients are injected through the wells to the subsurface. These nutrients stimulate autochthonous microbial populations. This technique is only effective if the hydraulic conductivity in the same in the activated zone as it is in the surrounding aquifer.

Bioscreens are an attractive treatment option because they have high longevity, no significant maintenance, and no nutrient replenishment. These screens are composed of organic wastes and limestone. The organic wastes not only serve as a high permeability structure, but also as a source of nutrients and bacteria. The bio screens also have high contaminant retentions and increased bioactivity. The hydraulic conductivity of the material in the bio screens is 10 times higher than that of the surrounding aquifer. The thickness of the bio screens depends on groundwater flow rates, the contaminant concentrations, and the degradation rates.

Phytoremediation is an in situ technique that uses plants to remediate contaminated soils. Phytoremediation is most suited for sites where other remediation options are not costs effective, low-level contaminated sites, or in conjunction with other remediation techniques. Deep rooted trees, grasses, legumes, and aquatic plants all have application in the phytoremediation field. Phytoremediation has been used to remove TPH, BTEX, PAH, 2,4,6-trinitrotoluene (TNT), and hexahyro-1,3,5-trinitro-1,3,5 triazine (RDX).

Plants are able to remove pollutants from the groundwater and store, metabolize, or volatilize them. Also, roots also help support a wide variety of microorganisms in the subsurface. These microorganisms can then degrade the contaminants. The roots also provide organic carbon sources to promote co metabolism in the rizosphere. The rizosphere is the soil in the area of the vegetative roots.

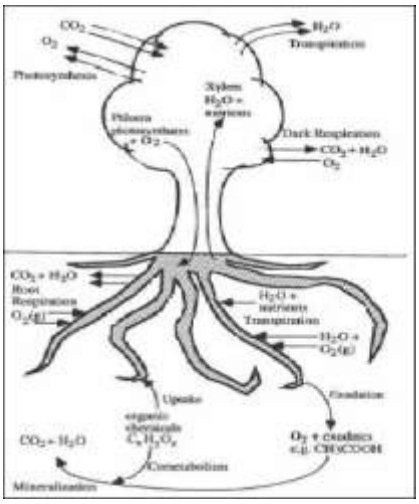


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Figure: 7illustratesdifferent phytoremediation techniques.

CONCLUSIONS

Many processes are explained in the paper above. Choosing the process that is “best” can be a difficult task. “Proper evaluation of bioremediation options begins by determining what constitutes an acceptable cleanup goal; for example, one must determine whether destruction, detoxification, or physical removal of the chemical target(s) is the goal of the remediation. Only after making this decision can one choose, design and conduct an appropriate means of bioremediation.”

As state many times before, in situ techniques have the advantage that the soil does not have to be removed or transported, but the techniques lack contaminant removal efficiency. Ex situ techniques remove are more effectively remove the contaminants, but sacrifice economic feasibility due to the costs involved with excavating and transporting the soil. The question becomes, how much can one afford to spend in order to increase the effectiveness of the remediation technique? A summary of which techniques remove specific compounds and which soil parameters are necessary for remediation is shown below in the difficult part of evaluating bioremediation techniques is that there are no standard criteria for evaluating among methods. This hurdle can be attributed to each site being different. The applicability of bioremediation techniques requires particularly close evaluation of each site. Soil conditions such as porosity, pH, moisture content, and presence terminal electron acceptors all affect which remediation technique can me used. Technique selection also depends on the pollutant that is targeted. Soil conditions, the presence of microbes, and the presence of pollutants must be measured in a treatibility study. These studies take time and money and cause some opposition to bioremediation. (Boopathy, 2000). Table 2 provides a cost comparison for common remediation techniques and some of the conditions of the cost analysis.

Contrary to what some people in the industry believe, bioremediation really does work to remove many different pollutants for soils. One of the greatest obstacles to overcome is the need for an engineering and scientific knowledge base. For bioremediation to be successful, researches, regulators, design engineers, and contractors need to understand the basic science behind these techniques and how that science can be applied to specific contaminated sites.

Another obstacle hindering wide scale bioremediation application is regulatory factors. The government regulates how a waste must be cleaned up. Because bioremediation is a relatively new technique compared to more established methods such as chemical and thermal removal methods, and the government sees encouraging bioremediation as a risk. If bioremediation of a certain site does not meet certain clean up goals set forth by a certain time, it is seen as a greater liability. The government also has many health and safety regulations to control the remediation processes. In addition, because microbes are injected into the soil that some crops are grown in, the Food and Drug Administration regulates soil remediation techniques as well. Genetically engineered microorganisms are also regulated through the toxic substance control act. Due to all of the “red tape” surrounding bioremediation regulations, some design engineers have avoided bioremediation processes

Due to the fact that specific microorganisms are needed to remove specific contaminants much more basic research is needed to find matches between the two. The money for this type of research and development is quickly disappearing. Bioremediation at this time does not turn a high profit, so many venture capitalist are looking to other technologies to invest in. Because of this, the research and development on bioremediation is much slower than that of other technologies. Academia may also be partially to blame for the skepticism behind bioremediation. No universities offer a program for bioremediation engineering.

Bioremediation needs people with a background in geology, hydrogeology, microbiology, environmental engineering, ecology, and geotechnical engineering. A person with one of those degrees must receive years of field experience before being properly trained to fully perform in the bioremediation field

As research and development of bioremediation slowly continues and becomes more proven to work, the government is easing their regulations of the use of this technology. (Boopathy). Research will continue and eventually bioremediation will become easier and more time and cost effective. More and more matches between microorganisms and the contaminants they can remove will be made. Eventually a standard method of directly comparing bioremediation techniques will be developed. It is also that hope that eventually microorganisms will be able to make in situ bioremediation more efficient at degrading contaminants to make it the front runner in bioremediation techniques. For now, the industry is left with the task of choosing between the degree of biodegradation and cost effectiveness of the method.

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