Chapter 25

Bioremediation of Marine Oil Spills

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Abstract

In this paper I will define bioremediation, provide background on how bioremediation works and some of the other alternatives. I will also discuss the application of this technology in the first year after the Exxon Valdez oil spill.

In the simplest terms, bioremediation is the use of microorganisms (fungi or bacteria) to decompose toxic pollutants into less harmful compounds. In this paper, the term bioremediation is used in the context of promoting the degradation of petroleum hydrocarbons or simply just crude oil.

To fully understand bioremediation we must discuss the term biodegradation. Biodegradation is a natural process by which microbes alter and break down oil into other substances. The resulting products can be carbon dioxide, water, and simpler compounds that do not affect the environment.

Bioremediation is the optimization of biodegradation. This acceleration can be accomplished by two forms of technology: (1) fertilizing (adding nutrients) and/or (2) seeding (adding microbes). These additions are necessary to overcome certain environmental factors that may limit or prevent biodegradation.

The study of bioremediation is not complete without a discussion of its practical applications. The Exxon Valdez oil spill was the largest oil spill in U.S. waters, and this is why I chose this as a case study, and it resulted in the largest bioremediation project ever. Scientists from around the world studied the use of bioremediation to clean up oil spills.

Bioremediation is not limited to marine oil spills; it has potential to help clean up land oil spills, pesticides and hazardous waste. There are also benefits to bioremediation such as saving money, being ecologically sound, destroying contaminates (not moving them from one medium to another) and treating waste on site.

The application of bioremediation will be an important aspect of waste management now and into the future as more is learned about this technology.

Keywords
Bioremediation, Marine Oil Spills, Biodegradation, Exxon Valdez

Introduction

Bioremediation can be a cost-effective technology (see figure 1), that is often used to treat oil spills in all types of environmental media including soils, groundwater, and surface water (both freshwater and marine). In this paper we will be looking at the bioremediation of marine water. Bioremediation is also used to treat oily wastes. Once spilled, oil is subject to a wide range of physical, biological and chemical weathering processes that helps break down the oil into other less toxic compounds in the environment. Weathering will be discussed later in the paper. Biodegradation is unique because it is the primary process by which the oil is actually removed from the environment. Most of the other processes involve the transfer of oil from one medium to another, such as evaporation, which transfers it to the atmosphere or dilution, from wave action, which transfers it throughout the marine environment. Due to the obvious benefit of actually removing the oil from the environment and the fact that it can be cost effective compared to other treatment technologies, biodegradation has been, and currently remains, the subject of considerable research. Crude oil and refined oil products are frequently stored and transported on or over land, and as a result, oil spills that impact soil and groundwater tend to be quite common although usually smaller in volume, mainly because of the vast amount of oil that is shipped in barrels over the oceans. In this paper we will be looking at the different types of research on marine biodegradation and will touch on the different types of other biodegradation.

Research on bioremediation in surface soils is currently focused on increasing the biodegradation rate, and restoring the site after the remediation is complete. Research on biodegradation in marine environments has studied the use of surfactants, fertilizers, and exogenous microbes, which are microbes that are not found naturally, and has found that only the use of fertilizers consistently increased biodegradation rates.

Figure 1

Method	Cost (USD)
Incineration	400-1200
Washing	200-300
Bioremediation	20-200

(TERIVISION)

Bioremediation Overview

Now that I have introduced you to bioremediation I will now give you an overview on bioremediation. Bioremediation was first discovered in the early 1980's and very little was know about how exactly the toxic waste was interacting with the hydrosphere. The first and best documented case involving bioremediation happened in 1979 when a pipeline carrying crude oil broke and contaminated an aquifer in Bemidji, Minnesota (Toxic Substances Hydrology Program). The site provides a unique opportunity to study a contaminant plume where the location, amount, and timing of the spill are precisely known. The study focuses on how crude oil spreads in soil vapor and ground water. Models have been developed to describe the controlling physical, chemical, and biological processes. These models can be used to evaluate remedial strategies for oil spills, including intrinsic (Toxic Substances Hydrology Program).

Biodegradation is a natural process than can be used to enhance the rate at which microbes biodegrade organic chemicals that have been released into the environment. The rate at which biodegradation will occur can be increased by providing an optimal living environment for the microbes. According to our lecture in class, most microbes that degrade petroleum hydrocarbons require oxygen, water, an acceptable temperature and pH range, and nutrients such as nitrogen and phosphorous. When the microbial environment is optimized by having the right amounts of water, air and nutrients and by maintaining proper acidity, biodegradation rates will be faster (Office of Technology Assessment).

Bioremediation works when microscopic organisms (microorganisms of fungi or bacteria) that live in soil and consume chemicals, such as petroleum hydrocarbons. In table #1 some of the major oil-degrading bacteria and fungi are listed. They use certain petroleum hydrocarbons as their food source and leave other chemicals behind, and will break down the hydrocarbons into water and carbon dioxide as their waste products.

The objective of bioremediation is to exploit naturally occurring biodegradation processes to clean up contaminated sites. There are several types of bioremediation. In situ bioremediation is the in-place treatment of a contaminated site. Ex situ bioremediation may be implemented to treat contaminated soil or water that is removed from a contaminated site. Intrinsic bioremediation or natural attenuation is the indigenous level of contaminant biodegradation that occurs without any stimulation or treatment (Maier, Pepper, and Gerba). In this paper we will be concerning ourselves with the in situ bioremediation of marine oil spills.

Table #1 - Major Genera of Oil-Degrading Bacteria and Fungi (G.D. Floodgate)

Bacteria	**Fungi**
Achromobbacter	*Allescheria*
Acinetobacter	*Aspergillus*
Actinomyces	*Aureobasidium*
Aeromonas	*Botrytis*
Alcaligenes	*Candida*
Arthrobacter	*Cephaiosporium*
Bacillus	*Cladosporium*
Beneckea	*Cunninghamella*
Brevebacterium	*Debaromyces*
Coryneforms	*Fusarium*
Erwinia	*Gonytrichum*
Flavobacterium	*Hansenula*
Klebsiella	*Helminthosporium*
Lactobacillus	*Mucor*
Leucothrix	*Oidiodendrum*
Moraxella	*Paecylomyces*
Nocardia	*Phialophora*
Peptococcus	*Penicillium*
Pseudomonas	*Rhodosporidium*
Sarcina	*Rhodotorula*
Spherotilus	*Saccharomyces*
Spirillum	*Saccharomycopisis*
Streptomyces	*Scopulariopsis*
Vibrio	*Sporobolomyces*

Alternative Techniques

Now that you have a good background on bioremediation I will tell you about some other techniques of oil removal. I will explain the advantages and disadvantages of all and why bioremediation is a better choice in oil removal.

Mechanical containment and recovery

Skimmers

A skimmer is a device for recovering spilled oil from the water's surface (Global Marine Oil Pollution Information Gateway). Skimmers may be self-propelled, used from shore, or operated from ships. The efficiency of skimmers is highly dependent upon conditions at sea. In moderately rough or choppy water, skimmers tend to recover more water than oil, mainly because of the waves spilling over the barriers. There are three types of skimmers, there is a weir skimmer, oleophilic skimmer and suction skimmers and each is described below. Each type offers advantages and drawbacks depending on the type of oil being recovered, the sea conditions during cleanup efforts, and the presence of ice or debris in the water.

Weir skimmers, as seen below in figure 2, use a dam or floating barrier to trap or contain the oil. The oil floating on top of the water will spill over the weir and be trapped in a skimmer inside. The trapped oil and water mixture can then be pumped out through a pipe or hose to a storage tank for recycling or disposal. The main advantage of this type of skimmer is that, the oil that is collected can be recycled. A couple of disadvantages of this type of skimmer is that it can mainly be used on cal waters and it is prone to becoming jammed and clogged by floating debris especially ice.

Figure No. 2 (Global Marine Oil Pollution Information Gateway)

Oleophilic, oil-attracting, skimmers, as seen below in figure 3, use belts, disks, or continuous mop chains of oleophilic materials to blot the oil from the water surface. The oil is then squeezed out or scraped off into a recovery tank. One advantage or Oleophilic skimmers is that they can be used on rough or choppy seas. Another advantage of Oleophilic skimmers is that they can be used on many different types of oil thicknesses. Some types of skimmers, such as the chain or "rope-mop" skimmer, work well on water that is cluttered with debris or rough ice.

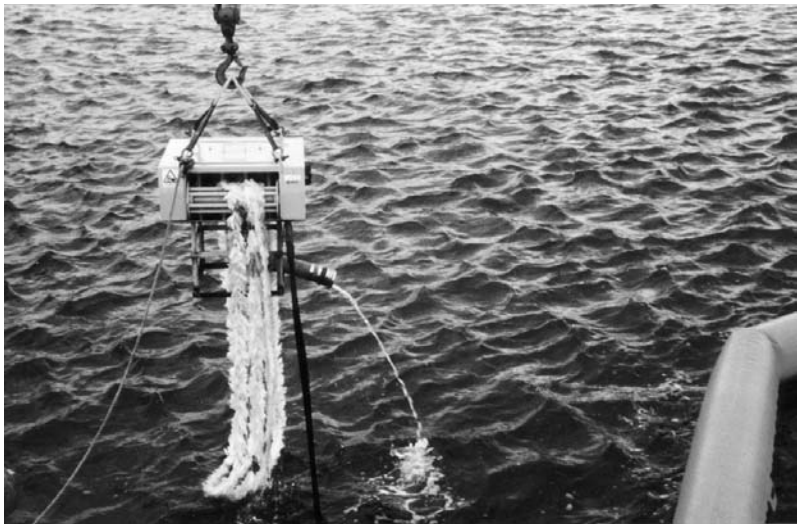

Figure No. 3 (Global Marine Oil Pollution Information Gateway)

Suction skimmers, as seen below in figure 4; operate similarly to a household vacuum cleaner. Oil is sucked up through wide floating heads and pumped into storage tanks. Although suction skimmers are generally very efficient, one disadvantage is that they are vulnerable to becoming clogged by debris and ice and require constant skilled observation. Suction skimmers do not do very well in rough or choppy water because the wave action will force more water than oil into the skimmer. Suction skimmers operate best on smooth water, where oil has collected against a boom or barrier.

Figure No. 4 (Global Marine Oil Pollution Information Gateway)

Dispersants

Once oil has spilled, people use oil spill countermeasures to try to reduce the adverse effects of spilled oil on the environment. Dispersants are one kind of countermeasure. They are chemicals that are applied directly to the spilled oil in order to remove it from the water surface, where oil can be especially harmful. In the figure below, the illustration shows how the dispersant is added to the water and what the mixture looks like.

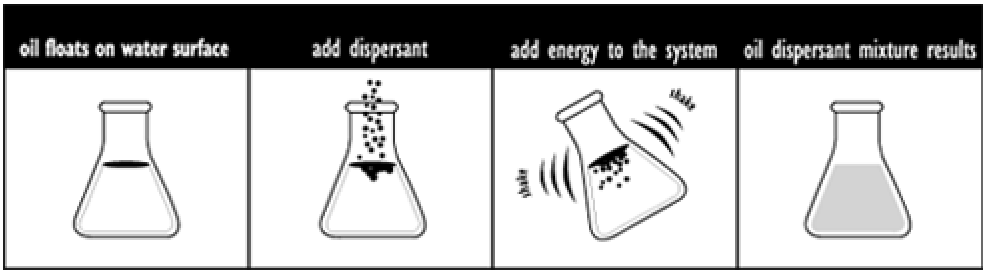

Figure No. 5 (Office of Response and Restoration)

Bioremediation and alternative bioremediation approaches

Bioremediation: Advantages and Disadvantages

Table No. 2 (Office of Technology Assessment)

Advantages:
- Usually involves only minimal physical disruption of a site
- No significant adverse effects when used correctly
- Helpful in removing some of the toxic components of oil
- Offers a simpler and more thorough solution than mechanical technologies
- Less costly than other approaches

Disadvantages:
- Undetermined effectiveness for many types of spills
- Takes time to work
- Approach must be specific tailored to each spill
- Optimization requires lots of information about spill site.

Nutrient Enrichment:
- Intended to overcome the chief limitation on the rate of the natural biodegradation of oil
- Most studied of the three approaches and currently seen as the most promising approach for most types of spills
- No indication that fertilizer use causes algal booms or other significant adverse impacts
- In Alaska tests, fertilizer use appeared to increase biodegradation rate at least by a factor of two

Seeding:
- Intended to take advantage of the properties of the most efficient species of oil-degrading microorganisms
- Results of field tests of seeding have thus far been inconclusive
- May not be necessary at most sites because there are few locales where oil-degrading microbes exist
- Requirements for successful seeding more demanding than those for nutrient enrichment
- In some cases, seeding may help biodegradation get started faster

Genetically engineered microorganisms:

- Probably not needed in most cases because of wide availability of naturally occurring microbes
- Potential use for components of petroleum not degradable by naturally occurring microorganisms
- Development and use could face major regulatory hurdles

Even though there are different types of techniques available, the best technique is bioremediation. The main reason that I believe makes bioremediation the best, is that bioremediation completely removes the oil from the environment instead of transferring it from one medium to another. The mechanical containment and recovery devices are great if you are trying to recover the oil in very calm waters, but they are often very costly. The dispersion technique doesn't really clean-up the environment, but rather dilutes the oil and transfers the oil from one medium to another. Bioremediation changes the chemical composition of the oil into water and carbon dioxide as the bacteria consumes it.

You now know that bioremediation is the best choice when you are trying to completely remove the oil form the marine environment. You may also be wondering how you know when you should use bioremediation as opposed to other options. Luckily I came across this flow chart, from the Environmental Technology Research Group, and that the chart explains what process you should use.

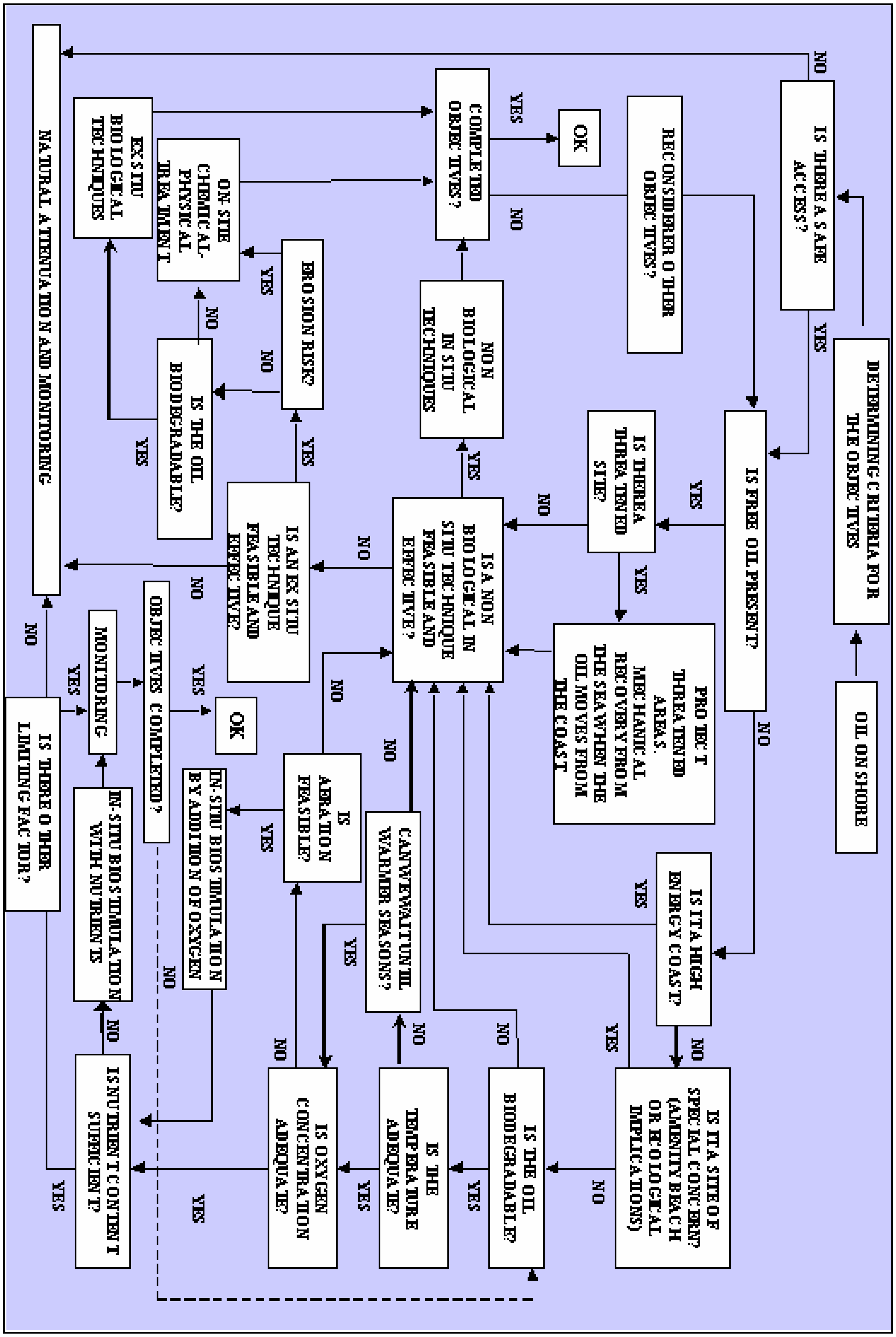

Figure No. 6 (Environmental Research Group)

Now that you know about the background of bioremediation, and how to select the right type of bioremediation for the situation I'm going to talk about the Exxon Valdez case study and what was used and what was learned in each.

Case Study

Exxon Valdez

In March 1989, 33,000 tons of crude oil was spilled from the Exxon Valdez in the Prince William Sound, Alaska (Maier, Pepper, and Gerba). A few days later there was a storm that helped spread the oil westward all along the Kodiak Island (shown below). Since the spill was spreading very fast, Exxon and the Environmental Protection Agency (EPA) soon reached a cooperative agreement in May of 1989 which allowed the use of bioremediation to be tested (Maier, Pepper, and Gerba).

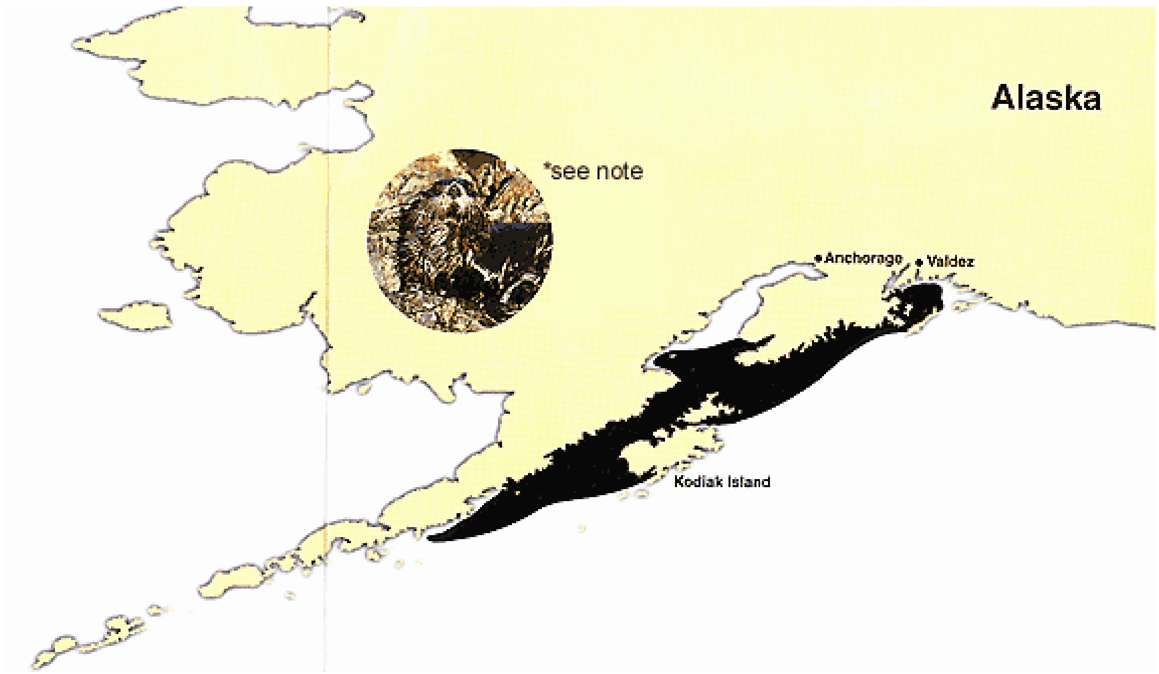

Image No. 1 ((Environmental Research Group)

But before bioremediation could be tested, some questions were needed to be addressed. Could bioremediation work in an environment so cold? Were there favorable conditions for degradation of petroleum hydrocarbons? Is Prudehoe Bay Oil (type of oil that was spilled) of sufficient quality for biodegradation? These issues were important if bioremediation was going to be used, especially since that is what I stated earlier in the paper about the disadvantages of bioremediation.

For the first question, scientists have found naturally occurring oil-degrading microbes in the environment so the cold is not a factor (Office of Technology Assessment). The next question is that if there were favorable condition for biodegradation, such as enough nutrients, oxygen and a carbon source. Since oil is high in hydrocarbons, there is a readily available carbon source. Since the entire question had been answered and everything looked like it would work, microbes were already biodegrading the oil.

Bioremediation technologies for beach cleanup have thus far received the most attention. Experiments conducted by the EPA, Exxon, and the State of Alaska on cobble beaches fouled by oil from the Exxon Valdez indicated that the addition of nutrients ate least doubled to quadrupled the natural rate of bioremediation (Office of Technology Assessment). As you can see from the figure on the next page, adding fertilizer has greatly increased the rate of bioremediation.

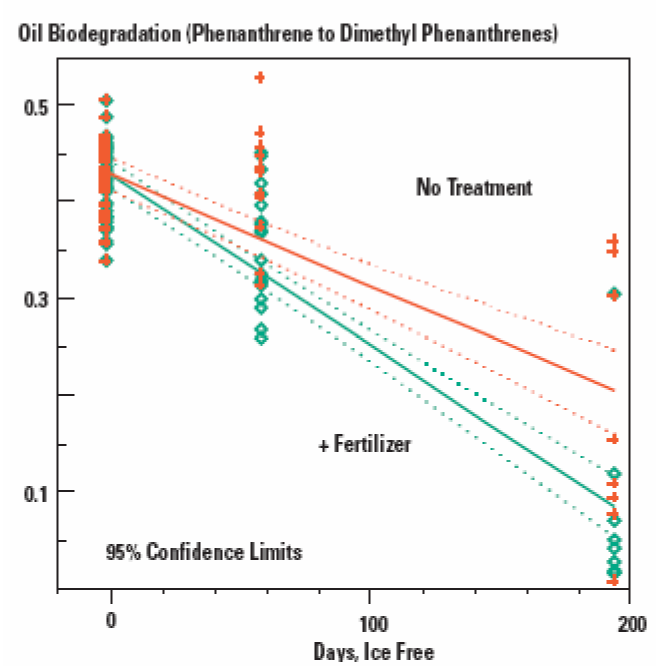

Figure No. 7 (Office of Technology Assessment)

Summary and Findings

Biodegradation is a natural process, and there is no question that, with enough time, microorganisms can eliminate many components of oil from the environment. Bioremediation is not only used to clean up after oil spills, but may also be used to clean up other environments. The EPA claims that bioremediation is a technology with enormous promise for the future (Riser-Roberts). The process of bioremediation is similar to wastewater treatment where we rely on microbes to clean our water for us. As long as we give them a favorable environment they do a pretty good job.

Some of the areas where bioremediation is still relatively new but it has the potential of saving money, being ecologically sound, destroying contaminates and allowing for the treatment waste on site. The application of bioremediation will be an important aspect of waste management now and into the future.

Although bioremediation holds great promise for dealing with intractable environmental problems, it is important to recognize that much of this promise has yet to be realized. Specifically, much needs to be learned about how microorganisms interact with different hydrologic environments. As these understandings increase, the efficiency and applicability of bioremediation will grow rapidly. Because of its unique interdisciplinary expertise in microbiology, hydrogeology, and geochemistry, the United States Geological Survey and the EPA will continue to be at the forefront of this exciting and rapidly evolving technology.

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