December 2009

Oil Pollution in Ecuador: A Devised Remediation Approach

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Oil Pollution in Ecuador:

A Devised

Remediation Approach

An Interactive Qualifying Project Report
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ABSTRACT

Research is required to remediate the oil contamination left by Texaco in Ecuador and its effects. These effects and potential methods of their remediation are analyzed with respect to water, soil, and the affected indigenous peoples. We propose a five-part approach to the contamination, the Five Components of Remediation, which is divided into the Primary Component, Site Assessment, and the Four Ancillary Components: Water Treatment, Source Removal, Soil Treatment, and Minimization of Psychological and Sociological Impacts.

ACKNOWLEDGEMENT

Without the contributions of many individuals and organizations, this project would not have been possible. Many thanks to Congressman Jim McGovern, his legislative director Cindy Buhl, and the rest of his staff for facilitating the creation of the project. We would like thank the Washington Office on Latin America for providing work space and connections. Our appreciation goes out to Doug Beltman of Stratus Consulting and Mark Quarles of eTech International for sharing their technical knowledge and their professional input. Finally, we would like to thank the project advisors for their assistance and guidance throughout the project experience.

AUTHORSHIP PAGE

The signatures below verify that work relating to this report was completed collectively. Each section of the final report was completed with the collaboration of all group members signing below. Chris Baker, Chad Caisse, and Ben Johnson each contributed equal efforts in the research, writing, and editing of the final report.

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Executive Summary

There is an estimated 3.8 million cubic meters (Cabrera, Cabrera Report: Appendix N, p. 3) of oil related pollution in the northeastern region of Ecuador. From 1964 to 1992 Texaco, now owned by Chevron, extracted oil from reservoirs underneath the Amazon rainforest in Ecuador and carelessly discarded the drilling fluids and solids associated with oil extraction in pits throughout the forest. In addition, Texaco's processing stations pumped wastewater into the local water systems. The careless dumping of 18 billion gallons of wastewater and 17 million gallons of waste oil (T.R.A.G., 2008, *Environmental Consequences of Oil Exploration*) has yet to be properly assessed or remediated, and hundreds of thousands of indigenous peoples have suffered as a result.

In this report we identify the main components of pollution remediation and provide direction for future research in each of these areas with respect to the oil contamination in Ecuador. Our findings result from analysis of documents specific to the oil contamination in Ecuador and those directly pertaining to general oil pollution, remediation, and the characteristics of tropical regions that may impact both. We also corresponded with individuals who have had experience in the affected region and experts in fields applicable to remediation. An important resource for the development of our findings was the Cabrera Report, a document created by the court appointed expert, Richard Cabrera, to evaluate the pollution and estimate the cost of its remediation. We found this document to be incomplete and have used its recommendations to compare the findings of our own research.

We believe there are Five Components of Remediation and have identified the initiating, or Primary Component, as Site Assessment. A full analysis of the pollution is vital to the cleanup effort and as shown in Figure 1below, should be used to illuminate a plan of action. The Cabrera Report does not fulfill the requirements of this component, and serves mostly as proof of the pollution's existence and the need for its remediation. In this report, we identify assessment technology, the uses in which their functionalities are optimized, and methods of application that we believe may provide the most complete vertical and horizontal representation of the pollution and its migration.

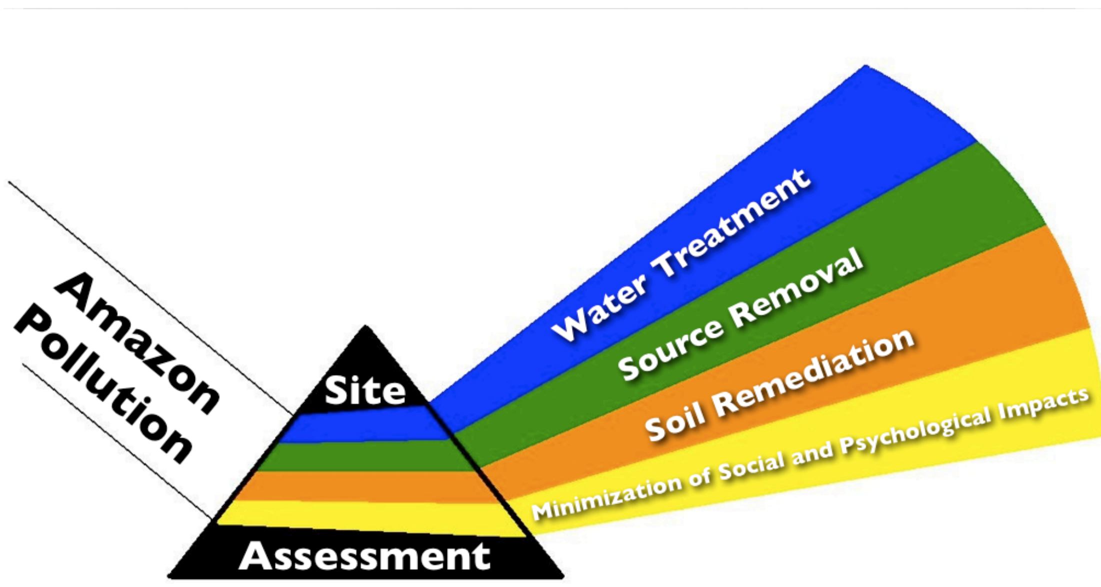

Figure 1: Site assessment as a means for remediation development

Site Assessment is followed by Four Ancillary Components. These components are Water Treatment, Source Removal, Soil Treatment, and Minimization of Psychological and Sociological Impacts. All four components are interrelated, and therefore would be most effective if addressed concurrently. We acknowledge that a lack of adequate resources may prevent this and thus have prioritized the ancillary components using the hierarchy of needs devised by Abraham Maslow (1943, PsychClassics). According to this theory the most basic needs must be addressed and satisfied before addressing more complex needs.

Water Treatment is prioritized as the first ancillary component of remediation because it is a basic physiological need. The method of attaining clean water currently in use by the affected peoples is a rainwater catchment system. We identify this system as inadequate in its current state and propose further research into a wider scale implementation. We also detail the regional water treatment method proposed by Richard Cabrera and propose research into community scale water treatment as a compilation of positive attributes of both methods. Further research into these methods will be required to identify which is the most effective and can be quickly implemented using local materials.

The ancillary component prioritized as second is Source Removal. There are 916 unlined open-air waste pits spread out over the northeastern region of Ecuador (Beltman, 2009, personal presentation). These pits contain a variety of contaminants that leak into the ground and surface waters. Removal of these contaminants will aid the remediation of both water and soil but will not have an immediate effect on the basic needs of the affected peoples. We propose research into removing the contents of these pits and treating them at an offsite location which has yet to be determined.

The third ancillary component of remediation, Soil Treatment, addresses the need for security as identified by Maslow (1943, PsychClassics). It is the most complex physical remediation component, but its major effect on people is through its impact on the ecology of their environment and not through direct contact. The remediation of soil addresses the need for security because the people will not feel safe eating crops or hunting animals until they are sure contaminants are no longer polluting the ecology of their community. In this paper, we identify methods of soil remediation and propose research into the combined use of soil vapor extraction, bioremediation, and phytoremediation. This combination may resolve the problem of the Ecuadorian Amazon's impermeable clay layer.

The final ancillary component of remediation is Minimization of Psychological and Sociological Impacts. This component is considered the most complex because it is not as easily or directly remediated as physical and security needs. Stresses on the mental health of the affected peoples are the result of harm to the culture with which they identify and the natural resources they value. In addition, stresses are created when the mechanisms they use to retain their identity and resources are threatened. The physical remediation will return their natural resources, and involvement in the development of a remediation plan may heal the psychological and sociological mechanisms they use to protect their way of life.

1. Introduction

Oil production is one of the largest and most profitable industries in the world. Last year, in *Fortune* magazine's annual rank of the 500 largest companies in the world, oil companies held seven of the top ten positions (Abkowitz, *Global 500*). The products of oil refineries are extremely useful and have become necessities in modern society. However, when oil is improperly handled, it can be extremely hazardous to the environment and dangerous to human health. Oil spills and careless waste management of toxic byproducts from the refining process lead to extreme health problems for humans, animals and contaminates the environment. Oil spills are often unintentional and in most cases difficult to prevent. On the other hand, careless waste management is controllable, but sometimes oil companies choose not to take preventive measures because it may be costly and time-consuming to do so. To limit environmental impacts, governments need to enforce tighter restrictions on oil waste management and, more importantly, any sites containing oil pollution need immediate remediation.

In America, oil pollution is far less evident, but in less wealthy countries lacking strict oil development regulations and enforcement, the polluting effects of careless oil development are far more apparent. In 1964, oil production began in the pristine rainforests of northeastern Ecuador. However, in just 30 years, oil pits spread over an area the size of Rhode Island in the Amazon rainforest have leaked toxic waste into the streams and tributaries of the Amazon River due to careless oil waste management. Thousands of people from the native tribes of Ecuador have felt the harsh effects of the pollution. Many have suffered from illnesses caused by the pollution. They have been forced to relocate, often with little assistance from the government, and they have lost fertile land for farming.

There have been very ineffective attempts at remediating the soil and cleaning the groundwater, leaving a tremendous amount of work that still needs to be done before the land is once again safe and healthy. Remediation techniques are available for curing the damaged soil and groundwater, but not enough samples have been taken to assess the extent and characteristics of the contamination. Also, there is currently an extremely complex and ongoing investigation that is trying to determine who is at fault, delaying remediation efforts. An enormous amount of work remains to be done, but it is obvious to everyone involved that it is a necessity.

The problem in Ecuador is very complex because it has multiple dimensions. First there is the obvious environmental impact. Eighteen billion gallons of wastewater and 17 million gallons of waste oil have been carelessly and improperly dumped into unlined oil pits and the streams and rivers of northeastern Ecuador (T.R.A.G., 2008, *Environmental Consequences of Oil Exploration*). The oil pollution is so massive that the court case between Chevron and the indigenous people of Ecuador is the largest environmental litigation ever with a proposed fine of $27 billion. The second, and equally, if not more important dimension of the problem is the social impact that the pollution has had on the indigenous people of Ecuador. They have been forced to move away from their native lands, abandon their normal lifestyles, and many have died from rashes and cancers.

The focus of many people concerned with the oil pollution in Ecuador has changed from remediating the land, to the litigation between Chevron and the indigenous people of Ecuador. This shift of attention has lead to a gap in the research concerning the problem in Ecuador. Despite the ongoing lawsuit, the remediation of the contaminated land is still the most important outcome. Discerning which remediation technique is very difficult because so many aspects of life in the Amazonian rainforest were affected. In fact, the problem in Ecuador may call for a combination of different remediation techniques to effectively clean the environment. In addition, the polluted waterways need to be treated which poses separate difficulties from the soil remediation including trying to implement locally-applicable technology. Despite the complexities that exist in trying to remediate the Ecuadorian rainforest, there is certainly the potential for a solution, and anyone involved would agree that this should be done sooner rather than later.

The purpose of this project is to suggest the best way to remediate the oil pollution in northeastern Ecuador. Our analysis will take into account many factors that could affect such an enormous project including the region's geography, the Ecuadorian government and its involvement in oil waste management and regulation, Ecuador's economy, and the impacts pollution has had on the sociology of the indigenous people. Hopefully one day, sooner than later, our assessment will assist in determining the most appropriate means for curing the polluted lands and turning them back into the beautiful and habitable rainforest they once were.

2. Background

To fully understand the problem that exists in the Northeastern region of Ecuador, we developed a greater knowledge of Ecuador, oil, and the existing oil pollution in that area. This background details the geography of Ecuador and the living conditions of its people. This chapter also describes oil drilling and oil refining as well as the common pollutants that these two processes create. We also give a more detailed description of the current status of the environment in Northeastern Ecuador and the lawsuit involving Texaco. Finally, we cover remediation techniques that may prove useful to the problem in Ecuador.

2.1. Geography of Ecuador

Ecuador is a small country located between two very large nations. About the size of Colorado, Ecuador is bordered by Columbia to the north and Peru to the south. Located on the northwest coast of South America, it borders the Pacific Ocean. Ecuador consists of four major regions, three of which make up mainland Ecuador. The Amazon region, the Andes Mountains, and the Pacific Coast sit next to each other from east to west. The Galapagos Islands, also known as the "Enchanted Islands", make up the fourth region. The regions vary greatly in geography which is a draw for Ecuadorian tourism.

Unfortunately, oil companies such as Texaco and PetroEcuador have been drilling for oil in the northeast region of the country in the Amazon basin. This has disrupted the natural processes of the region's environment as well as caused extensive damage through pollution. The oil production facilities that Texaco built have forced many tribes from their land. The oil industry has most affected the Cofàn, Quichua, and Secoya tribes which are located in the northeast region of Ecuador. The territories of the major tribes in Ecuador can be seen in Figure 2. The pollution caused by oil production facilities has pushed indigenous Ecuadorians out of their original territories, changing their lifestyles dramatically. Furthermore, many parts of the region are unlivable because the mishandled oil waste invades the natural resources used by residents of that region to satisfy their basic needs.

2.2. Indigenous People of Northeastern Ecuador

Ecuador has been inhabited by indigenous groups for thousands of years and each group has very distinct tendencies and cultures. Some indigenous groups freely interact with the outside world, however some limit contact by locating themselves deep in the Amazon Rainforest. In the past, the indigenous tribes thrived off the ecosystem that they had become adapted to. Unfortunately, the human rights of these groups have been infringed upon in recent decades. One primary example of this is the arrival of Texaco in the northeastern region of the Amazon Rainforest. The three main tribes that have been affected by Texaco's oil production and the resulting oil pollution are the Siona-Secoya, Quichua, and Cofàn (see Figure 2). For a more in depth look into these tribes, refer to Appendices A through C. These tribes range in size with the Quichua numbering 2.5 million, the Cofàn with an estimated 1,000 and the Siona-Secoya with around 300, each tribe having their own skills. The Quichua once had a very elaborate infrastructure consisting of canals, mountain roads,

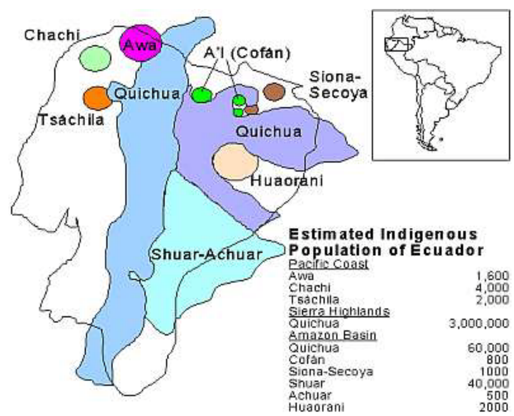

Figure 2: Location of Indigenous Ecuadorian Tribes (Equinox. (2008). *Multiethnic*)

systematic irrigation, and mountain terraces. The Cofàn were skilled craftsman and warriors working with stone to make very good tools which they used to build canoes and shelters. The Siona-Secoya focused on small sustenance farming and fishing. Although very different, these tribes did have similarities.

There are clear trends in the influences that outside civilizations have had on the tribes affected by oil pollution. For the tribes involved, the first major influence from the outside world was the arrival of the Spanish conquistadors in the 1500's. The affect the Spanish had on the indigenous tribes was not only cultural, but physical too. Missionaries who arrived with the Spanish intended to spread their religious beliefs. However, the missionaries spread small pox, measles, polio, whooping cough, cholera, tuberculosis, and malaria rapidly through indigenous territories. These diseases wiped out a great number of indigenous Ecuadorians leaving some tribes in danger of dying completely.

Giant oil corporations were the next major influence on the indigenous peoples. Although oil companies like Shell Oil Company had searched for oil prior to Texaco, Texaco arrived in the Amazon Rainforest on a scale that was previously unheard of. Not only did Texaco displace the tribes by drilling for oil on their land, but the pollution that they allowed to leak into the rivers also interrupted the people's lifestyle. Used for fishing, bathing, and transportation, the rivers and streams that flow through the Amazon Rainforest are the main source of life for the indigenous communities, and they are often located right on the riverbanks. The pollution of the rivers created and left by Texaco forced the indigenous tribes deeper into the rainforest to find clean water. If that were not enough, Texaco employees also physically harassed the members of the indigenous groups and baited them about their native dress.

Some tribes like the Cofàn fought back with force. Other tribes seemed to accept their fate, believing they were unable to fight back against a corporation as massive as Texaco. The current court case gave the indigenous people an opportunity to tell their side of the story and to fight for the ability to return to their preferred way of life.

2.3. Oil Extraction

Petroleum is one of the world's most valued resources. Industrialized countries cannot go through one day without oil or one of its byproducts. To fully understand oil pollution, it is important to understand where oil comes from and how it is extracted. Oil takes a very long time to generate and is composed of hydrocarbons. Hydrocarbons are organic compounds that are byproducts of the deterioration of algae, bacteria, and plant matter. A large deposit of hydrocarbons can lead to the formation of oil reservoirs which occur in areas where decomposing organic compounds can accumulate underground (Elsevier, 1983, p. 222). These areas include swamps and marshes that have been buried for thousands of years.

The other main factor in the development of an oil reservoir is its location underground. Oil mainly accumulates in sedimentary rocks. Sedimentary rocks are fragments of other rock that have been ground up and compacted into new structures. Oil reservoirs also occasionally occur in hollow areas in igneous rock—geologic formations formed from liquid material that cools over time (Elsevier, 1983, p. 38). Figure 3 shows a general formation that marks the likely location of an oil reservoir.

The use of oil dates back hundreds of years to Mesopotamia, Egypt, Persia, and China where they used oil for lighting and heating homes. Tar, a product of oil, was used in creating roads as well as in the construction of shelters. The oil industry has been consistently growing throughout history and from 1980 to 1990 the use of oil has grown from 400,000 barrels a day to 62.9 million barrels used each day (Elsevier, 1983, p. 3). This growth has resulted from many things including changes in the use of petroleum as well as oil's role in continued technological advances (Elsevier, 1983, p. 351). These main uses include roles in the automotive, marine and aviation industries as well as in domestic heating, everyday plastics and agriculture.

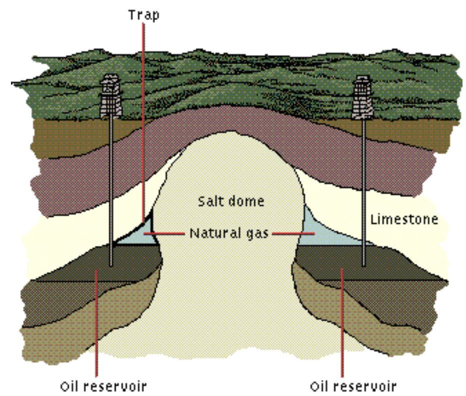

Figure 3: Common Oil Reservoir Diagram (Emt-india (2009) *Oil Drill Rig and Reservoir)*

2.3.1. Oil Exploration

Oil exploration begins with prospecting land believed to contain subterranean oil. The areas that are likely to hold oil are called "blocks" (Devereaux, 1998, p. 27). In Ecuador, like many other countries, the government retains ownership of subterranean land regardless of who owns the surface land. Rights to this subterranean land must be purchased from the government (Nersesian, 2007, p. 173). Companies search for blocks based on the belief that the many risks involved in drilling for oil are outweighed by the benefits that will be had upon discovery of oil.

It is important to understand the risks that are involved in oil exploration and oil production. Searching for oil can be expensive due to exploration, data acquisition, and development costs. Great improvements have been made to the technology used in detecting subterranean oil, but there is still no guarantee that a deposit will be found. If a deposit is discovered, there is also no guarantee it will contain oil or gas. The oil well could also produce too little oil to create profits. During drilling, gas may cause extensive damage to the drilling equipment if it is hit unexpectedly adding to the cost of exploration (Elsevier, 1983, p. 36). All of these costs combined with the chances that harm could occur to the equipment and the operators make drilling for oil a very risky investment. Taking these risks into consideration, oil can still be an extremely profitable endeavor.

The search for oil begins in a place believed to contain a high concentration of buried petroleum hydrocarbons (Devereaux, 1998, p. 15). Hydrocarbons are the decomposed remains of plants and animals. These remains will accumulate and form layers, which overtime can develop into oil fields. A well proposal is made after four main objectives are met (Devereaux, 1998, p. 28). First, gas and oil must be present. Second, the depth must be measured to the barriers between the gas and the oil as well as the oil and the water that are found in oil reserves. Then, core samples must be taken from the reservoir. The last objective is to test the oil reservoir to determine how it will react to oil production during and after drilling. The well proposal will also include main descriptions about the structure and location of the well in addition to the plans for the well during and after the drilling procedure. A drilling department will review the proposal to ensure safety and environmental consciousness.

2.3.2. Oil Wells

Two of the main factors in determining which oil rig will be chosen is the type of well that is being tapped and where the well is located, i.e. onshore or offshore.

Exploratory, appraisal, and production wells are the three main types of oil wells (Nersesian, 2007, p. 175). Exploratory, or wild-cat wells, are used for drilling in search of new oil by using a previous oil source as a reference. Appraisal wells, also known as development wells, are drilled branching out from a well where an oil reservoir has already been discovered. This is to determine the magnitude of the tapped oil well. They are normally abandoned soon regardless of whether they find or miss the reservoir. Finally, production wells are drilled as the main method of oil extraction. Texaco extracted approximately 220,000 barrels of oil per day from over 440 oil wells (ChevronToxico, 2009).

2.3.3. Oil Drilling

The first recorded rig used in drilling for oil was the cable tool system. This was a very simple system used in China around 300 AD. This simple device uses gravity and the repetitive dropping of a heavy bit into the ground (Elsevier, 1983, p. 122). This procedure can still be seen being used in pile drivers as a heavy weight is dropped onto a pipe that becomes submerged in the ground. A more modern example of this system used in the production of oil is the oil derricks seen all over Texas (Nersesian, 2007, p. 175). A steam engine drives a beam that rocks back and forth creating the same up and down motion.

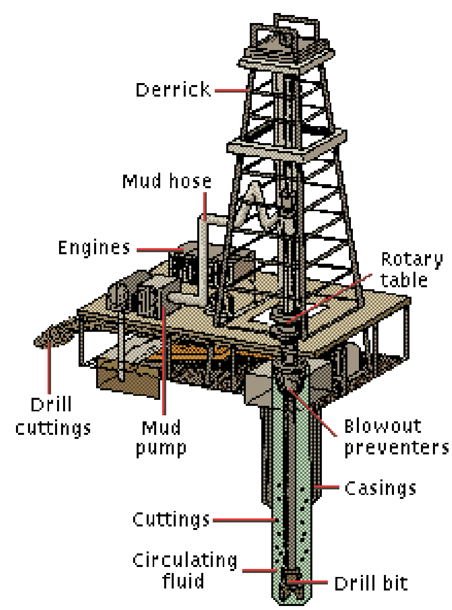

Figure 4: Rotary Drilling System (Emt-india (2009) *Oil Drill Rig and Reservoir*)

The most common drilling rig used today is the rotary drilling system. The drilling rig used in rotary drilling systems can be seen in Figure 4. A bit is rotated into the ground, grinding the rock beneath it. As the bit makes its way into the ground, it is led down by a shaft. This shaft serves three main purposes. First, it is used to rotate the bit. Second, it is used to retract the bit if needed. Finally, the shaft is used to pump the drilling fluid into the hole. Drilling fluid is used to pump out the material that has been ground down by the bit. This "drilling mud" is then pumped back out of the hole to ensure that the bit is efficiently grinding new material. This drilling system can bore through a few thousand feet of material per day (Nersesian, 2007, p. 175). Rotary drilling methods are much more efficient and can lead to much greater profits. This method also creates a great amount of excess waste, including the drilling mud and drill cuttings that must be dealt with.

2.4. Oil Processing

First, it is important to understand the difference between oil refining and oil processing. These terms are often confused. Oil refining is concerned with the separation of crude oil into its many different weights. These separate weights of crude oil serve different purposes. For instance petroleum, kerosene and lubricants are all products of crude oil but are only created after complex oil refining. Oil processing is required before oil refining. As oil is extracted from the ground, it is made up of three phases: gas, formation water, and crude oil. Oil processing is concerned with the separation of these three phases. On-site oil field processing is advantageous for three main reasons (Manning, 1995, p. 79). First, it is easier and less expensive to process or treat the gas, production water, and crude oil separately. Second, production water is corrosive and therefore removing it will prevent damage and allows for less resistant materials to be used in the crude oil pipelines. Finally, transportation of the three phases is much easier and more efficient when they are in their separate phases. This also allows for greater well production due to significantly lower pressure in the pipeline.

To separate the three phases of the incoming product, different combinations of separators can be applied for specific tasks. The main idea is to separate the gas from the liquid and then when the liquid is isolated, separate the crude oil from the production water (Manning, 1995, p. 80). To separate the gas from the liquid, all three phases are pumped into a separation tank. At the inlet of the tank, a baffling valve forces the liquid to spray, similar to when a thumb is placed over the end of a hose. This high pressure separation allows the majority of the gas to be freed from the liquid phases. The gas will rise to the top of the tank and out the gas outlet. From here, the gas will be flared or burned off.

After being forced past the baffling, the liquid phases will fall to the bottom of the tank and out the liquid outlet due to gravity (Manning, 1995, p. 81). At this point there are multiple ways of separating the production water from the crude oil. One simple and common method is centrifugal separation. Due to the different densities of the liquids, the production water (more dense) and the crude oil (less dense) will separate, at which time they can be pumped out in different pipes and sent for further processing. To cut further costs, Texaco used an even simpler method of separation. Doug Beltman stated that once the gas is removed from the solution, Texaco pumped the liquid phases into an unlined storage pond. The liquid sat in the ponds, and due to the different densities of the liquids, they simply separated themselves. Since crude oil is less dense than water, it floated to the top. Texaco was then able to pump the crude oil off of the top of the pond and send it to refining stations outside of the country. Texaco then dumped the remaining production water into the nearby rivers, streams, and soil. If this method was to be used successfully, Texaco would have first used lined pits, but more importantly, Texaco would have re-injected the production water back into the oil reservoir as is mandated by most government standards. However, Texaco did not abide by these environmentally friendly methods which resulted in the pollution that still exists there today.

2.5. Commonly Found Materials in Contaminated Soils

Drilling fluids are a major concern for any drilling operation. This concern is especially great while drilling on shore (World Bank Group, 1998, p. 359). Drilling mud, which is used for flushing out the debris ground down by the drill bit during drilling operations, is one of these drilling fluids. Drilling fluids commonly contain a freshwater gel, bentonite, water insoluble systems which can be made of up to 50% diesel fuel by volume, and salt water, either potassium chloride or sodium chloride. Other drilling wastes that can be found in drilling fluids are lubricants, and additives like polymers, oxygen scavengers, biocides, and surfactants. These additives and lubricants are used to aid in the decrease of friction while drilling, and to protect the drilling apparatus from bacteria and corrosion while it is submerged.

Drilling also produces a great amount of drilling solids. These solids can absorb the waste fluids or may suspend themselves in the drilling fluid solutions (World Bank Group, 1998, p. 359). Drilling solids that are commonly found on the drilling site can include borehole cuttings, drill cuttings, flocculated bentonite and weighing materials. These solids are all drilling mud sump materials and can be found at the bottom layer of the drilling fluids. Drilling often produces other pollutants such as used oils, cementing chemicals, and organic compounds that can be toxic. Solid wastes that are produced during drilling and refining operations that are non toxic are commonly used as backfill during on site construction. In Ecuador, every drill site has about 2 or 3 oil pits within a hundred yard of it. These pits primarily hold the drill cuttings, drilling mud, and crude oil that are not collected by the pipeline. Doug Beltman stated that soils at every one of the well and productions station sites sampled during the trial, contain elevated levels of petroleum hydrocarbons, and the levels at nearly all of the sites exceed Ecuadorian standards and some commonly used United States standards.

Normally, the onsite processing of crude oil is environmentally safe. Most government regulations require the reinjection of production water, or wastewater, back into the subterranean reservoir. Doug Beltman however, stated that Texaco used unlined ponds and carelessly disposed of the production water into the nearby rivers, streams and soils.

Wastewater typically contains very hazardous solids that are suspended in the solution and is the most prominent form of processing pollution (World Bank Group, 1998, p. 359). To prevent bacterial growth in the wastewater, harsh chemicals such as biocides are added. Hydrogen sulfide scavengers like sodium hypochlorite may also be added. After these chemicals are added, the waste water may be pumped back into the ground, usually under strict monitoring. Oil processing can also produce lead from the bottom of the processing tanks, emulsions, and heavy hydrocarbon residues that may contain Polynuclear Aromatic Hydrocarbons. Boiler water, scrubbing fluids and other wastes associated with steam production are also produced by processing plants. Table 1 displays a list of the common products found in the wastewater from the processing of crude oil.

Table 1: Wastewater Makeup from Crude Oil Processing (World Bank Group. (1998) p. 360)

Product	Typical Values in milligrams per liter (Averages)
Oil and Grease	7 – 1,300 (200)
Total Organic Carbon	30 – 1,600 (400)
Total Suspended Solids	20 – 400 (70)
Total Dissolved Solids	30,000 – 200,000 (100,000)
BOD	120 – 340
COD	180 – 580
Phenols	50
Cadmium	0.7
Chromium	2.3
Copper	0.4
Lead	0.2
Mercury	0.1
Nickel	0.4

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2.6. Oil Industry in Ecuador

Oil provides over 40% of Ecuador's export earnings and a third of government revenue (Quito, 2004, The Oil Industry in Ecuador). Oil is Ecuador's highest grossing export, and it has a direct relationship with the stability of their economy. In recent years, Ecuador has produced an average of over 530,000 barrels per day (bbl/d), half of which is consumed by the United States (Clough, 2007, Oil). Oil companies in Ecuador have never had trouble refining oil, but they have certainly struggled with disposing of the waste products properly. From 1964 to 1990, Texaco dumped more than 18 billion gallons of toxic wastewater into the Ecuadorian Amazon rainforest, leaving. Texaco took advantage of the loosely enforced oil regulations for decades, and it has resulted in an environmental catastrophe that experts have dubbed the "Rainforest Chernobyl" (ChevronToxico, 2009, Rainforest Chernobyl). Thousands of the indigenous people who lived in the oil refining region have been forced to relocate due to the environmental devastation in their once pristine homeland. There have been several inadequate attempts to remediate the land damaged by the oil waste, but there is still an estimated 3.8 million cubic yards of soil that require treatment. (Cabrera Report, Appendix N). The enormous amount of damage to the environment and human health has resulted in the largest environmental lawsuit in history, which has lasted for over 15 years. The case involves over 30,000 Ecuadorians who have been affected by the devastation in one way or another and the oil giant, Chevron, which purchased Texaco in 1992 (ChevronToxico, 2009, About the Trial). In recent years oil production in Ecuador has been strictly monitored, and proper techniques for waste disposal have been enforced. However, the damage from decades of improper oil refining operations is still obvious.

2.7. History of Oil Production in Ecuador

The exploration for oil in Ecuador began in 1964 and since then the production of oil has resulted in crude oil being the country's largest grossing export. For nearly three decades, Texaco and PetroEcuador were the only oil companies involved in oil production in Ecuador. After Texaco's departure from Ecuador in the early 1990's, many private foreign-owned oil companies took over oil production. The mass production of oil in Ecuador assisted in the beginnings of modernization for the country. However, an enormous amount of pollution has occurred as a result of oil mismanagement, damaging the rainforests of Ecuador and the health of its people.

2.7.1. The Ecuador Oil Consortium

In 1964, Texaco and the Ecuadorian government signed an exploration concession agreement which created a Consortium for oil development. "The Consortium originally consisted of two oil companies, Texaco and Gulf Oil, each holding a 50% share. However, in June of 1974 PetroEcuador, the state oil company of Ecuador acquired 25% of the Consortium. And in December of 1976, PetroEcuador acquired Gulf Oils remaining share in the Consortium, leaving Texaco with 37.5% share in the Consortium and PetroEcuador with the remaining share" (ChevronCorp., 2009, *Texaco in Ecuador*). This separation of power within the Consortium would be the cause of great debate when deciding who was at fault for the oil pollution that ensued.

2.7.2. The Texaco Years: 1964-1990

In 1964, Texaco, an American oil company with over 50 years experience in the oil business at that time, acquired a concession of more than 1 million hectares in Oriente, a region in the Ecuadorian Amazon (ChevronToxico, 2009, A Rainforest Chernobyl). Texaco spent its first eight years in Ecuador conducting preparatory work including drilling exploratory wells, developing the Trans-Ecuadorian pipeline, and building roads through the dense rainforest. It spent the next 18 years producing immense amounts of oil, during which time oil became Ecuador's largest export. Despite holding only a share of the Consortium, during Texaco's reign in Ecuador, "Texaco acted as the sole operator of the Amazon concession, designing and operating the entire oil production infrastructure" (ChevronToxico, 2009, *Historic Trial*).

From 1972 to 1990, Texaco extracted approximately 220,000 barrels of oil per day from over 440 oil wells. Estimates have shown that Texaco's total profits during this 18-

year span reached upwards of $30 billion (ChevronToxico, 2009, *Texaco's Fraudulent Remediation).* However, the environment suffered from mass pollution as the result of Texaco's incompetent oil waste management procedures. Texaco deliberately dumped waste byproducts from oil production into the Amazonian rainforest to cut costs of waste management. "The company admits during this time that it dumped 18 billion gallons of toxic waste in an area that was home to six indigenous nationalities – one of which is now extinct" (Texacotoxico, 2009, *The Trial*). Ecuador's government reaped enormous economic benefits from Texaco's vast oil production venture, however, the environment has been left in ruins.

Overall, Texaco drilled 356 wells and 22 processing stations while in Ecuador. Generally, 2 to 3 pits were dug near these well sites and processing stations, resulting in a total of 916 oil pits (Cabrera Report, Page 17). These oil pits still remain to this day, vacant, and leaking deeper into the soil and local waterways.

2.7.3. PetroEcuador Takes Over: 1990-1992

In June of 1990, PetroEcuador began the process of taking over all Texaco's oil operations in Ecuador, a process that would last two years. By July of 1992, PetroEcuador had officially assumed full control of Texaco's oil operations, leaving Texaco exempt from any future oil pollution or production. However, since PetroEcuador inherited the substandard infrastructure and technology of Texaco, the same substandard operations continued for several years until government regulations called for newer technology to be implemented (ChevronToxico, 2009, *Historical Trial*).

2.7.4. Oil Companies Involved After Texaco's Departure: 1992-Present

Since Texaco's official departure from Ecuador oil production in 1992, many oil companies, both Ecuadorian and international, have taken control of producing oil in Ecuador. PetroEcuador still stands as the most productive oil company in Ecuador, "responsible for 38% or the country's total crude oil production in 2005" (Clough, 2007). The remaining 62% belongs to 16 other oil companies operating in Ecuador. The largest is the foreign-owned private oil company, Occidental Petroleum, which represented 14% of crude oil production in the first half of 2005. The private sector, which includes Occidental, consists of 3 private Ecuadorian companies and 13 international private oil companies (Wise Earth, 2009). Figure 5 shows the production of crude oil in Ecuador. As you can see, the private sector makes up the majority of crude oil production, but since it consists of 16 different oil companies, PetroEcuador is actually the largest single producer of oil.

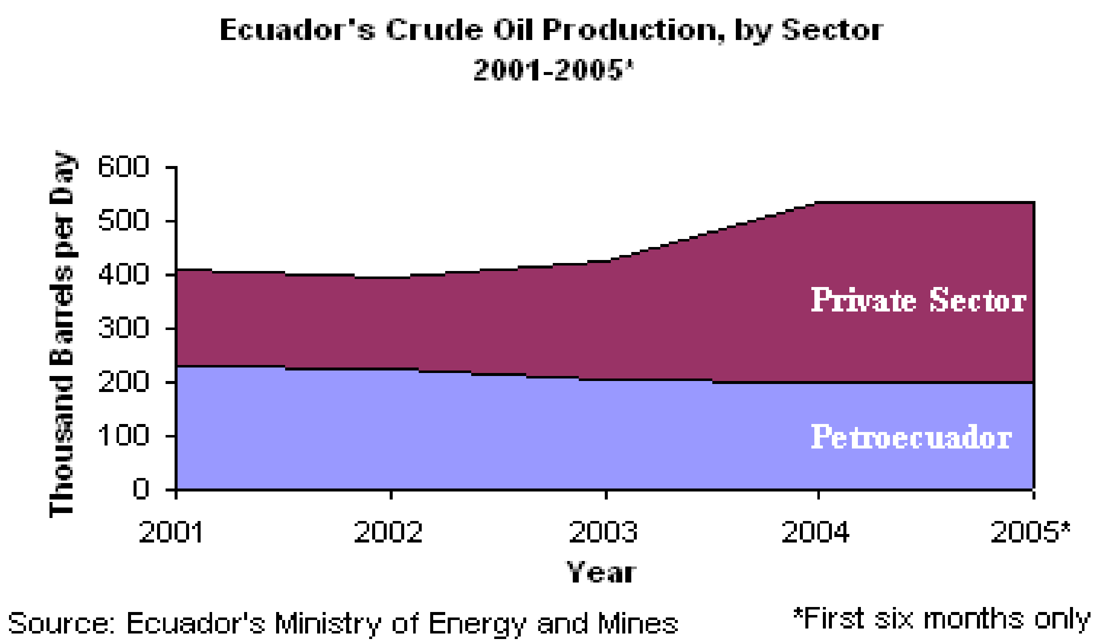

Figure 5: Ecuador's Crude Oil Production, by Sector (Clough, 2007, *Sector Organization*)

2.8. Impact of Oil Production on Economy

Oil production is the largest source of economic income in Ecuador, therefore it will continue despite the negative effects it has had on the environment. The oil sector dominates the Ecuadorian economy, accounting for 40 percent of export earnings and one-third of all tax revenues (Clough, 2007, *Oil*). In 2005, Ecuador ranked as the fifth-largest producer of oil in South America, averaging 538,000 barrels per day of oil (Clough, 2007, *Introduction*).

Ecuador produces quantities of oil that are much greater than they consume. This enables them to export nearly half a million barrels of oil daily, resulting in massive profits. Figure 6 displays the production rate of oil in Ecuador over the last 20 years vs. its consumption rate of oil. The difference between the two results is the total net exports. This amount of net oil exports, approximately 350,000 barrels per day in 2005, is a clear example of how important oil production is in Ecuador.

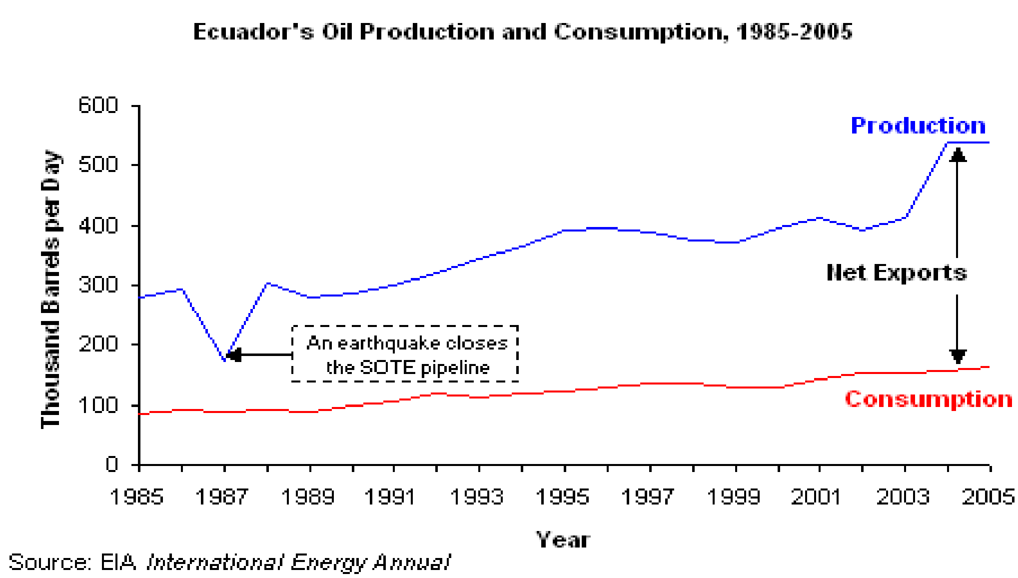

Figure 6: Ecuador's Oil Production and Consumption, 1985-2005 *(*Clough, 2007, *Sector Organization)*

2.9. Oil Pollution in Ecuador

Oil production has brought great economic benefits to Ecuador's government, but it has also brought devastation to the environment and grief to the people that inhabit the land. Oil companies, specifically Texaco (now Chevron), used faulty practices while extracting and transporting oil which has resulted in polluting the northeast region of Ecuador with billions of gallons of toxic wastewater and crude. The indigenous people of that area have been forced to relocate and many have developed illnesses from the toxic pollution. Figures 7 and 8 displays cancer rates while comparing exposed the non-exposed Ecuadorians. As a result, the people have filed a lawsuit against Chevron, which has become the largest environmental lawsuit in history.

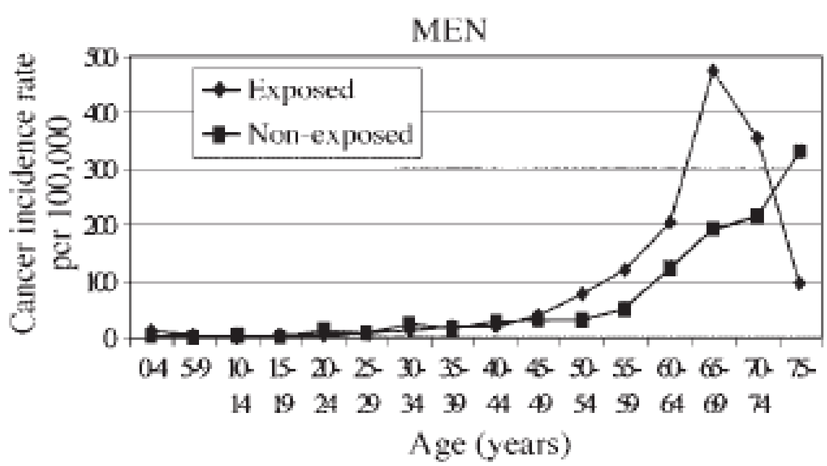

Figure 7: Cancer rates per 100,000 persons in exposed and non-exposed men (Doug Beltman, Stratus Consulting)

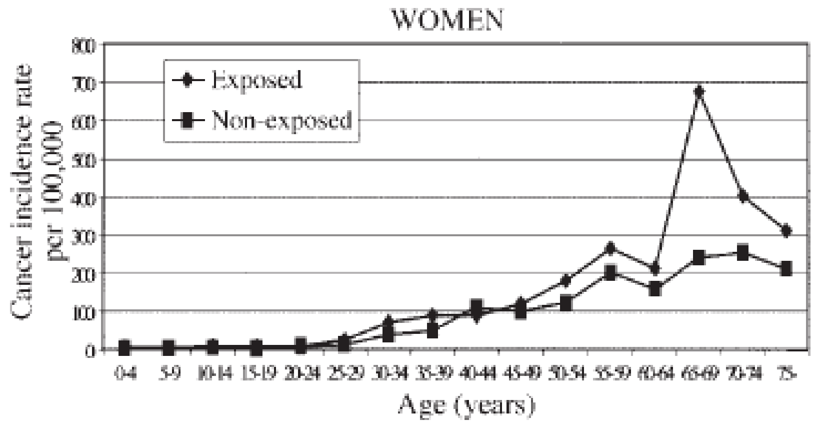

Figure 8: Cancer rates per 100,000 persons in exposed and non-exposed women (Doug Beltman, Stratus Consulting)

2.9.1. Lack of Government Control

Texaco was a well-respected American oil company when they began work in Ecuador and the government was quick to trust Texaco. Ecuador's trust in Texaco combined with their excitement to begin oil development within their country resulted in virtually no oversight of the production Texaco was running. "Texaco took advantage of limited Ecuadorian government oversight, and abused the trust of Ecuadorian oil officials, who assumed that an American oil major would employ the same state-of-the-art technology in Ecuador that it had developed and used at home" (ChevronToxico, 2009, *Chevron vs. PetroEcuador's Responsibility*).

Another reason Texaco was able to get away with polluting the environment for so long was because they were extracting oil from extremely remote and dense rainforest areas. And as long as they continued to produce profitable quantities of oil, the government didn't bother investigating.

2.9.2. Magnitude of Pollution in Ecuador

"During its operation in Ecuador Amazon until 1992, Texaco spilled **17 million** gallons of oil from its pipeline and dumped **18 billion** gallons of toxic waste directly into the rainforest, and thus contaminating 1,700 square miles [around 442,000 ha] of pristine Ecuador rainforest with extremely dangerous chemicals" (T.R.A.G., 2008, *Environmental Consequences of Oil Exploration*). Texaco deliberately ignored environmental controls and polluted the environment not only because they could but because it was cost effective. "Lawyers for the tribal leaders estimated that Texaco saved three to four dollars per barrel by dumping the wastewater into the ground rather than safely pumping it beneath the earth's surface, as it does in the United States" (Knight, 2002, *Amazon Leaders Press Case in U.S. Court*). During a span of three decades, Texaco constructed 916 open-aired, unlined pits to dispose of toxic waste. The toxins from this waste have seeped into the water table and now infect the rivers and streams that are such an important facet of Ecuadorian life. Texaco's greed resulted in billions of dollars worth of damage to the environment.

The two pictures seen in Figure 9 show the current state of two oil waste pits in Ecuador. The pollution is clearly visible in both pictures. These open, un-lined pits were used to dump toxic byproducts of oil production. Hundreds of pits just like these two are scattered throughout the northeast region of Ecuador.

Figure 9: Unlined Open-Air Oil Waste Pits in Ecuador (ChevronToxico, 2009, *Homepage*)

2.9.3. Impact on the Ecuadorians

The indigenous people of Ecuador have felt the impact of Texaco's faulty practices the hardest. Tens of thousands of native Ecuadorians have been forced to relocate because of uninhabitable land due to pollution. Many have suffered serious illnesses from unintentionally ingesting toxins from oil waste, and many have lost farmland and cattle, ruining the little source of income they used for survival (ChevronToxico, 2009, *Health Impacts*).

2.10. *Aguinda v. Texaco:* The Ecuadorian's Fight Back

The indigenous people have reacted to the abuse from Texaco with anger and resentment. In 1993, a class-action lawsuit was filed against Texaco by representatives of the Ecuadorian people to demand compensation for catastrophic damage caused by the malpractice of Texaco. The lawsuit is still ongoing and has become one of the largest environmental lawsuits in history. "This case is the first time indigenous people have forced a multinational corporation to stand trial in their own country for violating their human rights" (ChevronToxico, 2009, Historic Trial). If Texaco is found guilty of being responsible for the oil-related devastation to the environment and the countless health problems for the people, they face a fine of up to $27 billion - “the largest environmental damages award in history” (ChevronToxico, 2009, Damages Assessment). The case involves over 30,000 indigenous people and “victory for the Ecuadorian plaintiffs will set a vitally important precedent for environmental justice cases everywhere” (ChevronToxico, 2009, About the Trial).

2.11. Texaco Remediation Efforts

The foundation of Texaco’s defense in the lawsuit lies in an inadequate $40 million remediation they performed in Ecuador from 1990-1998. They claimed that this remediation cleared them from any future responsibility in Ecuador. However, the “clean-up” they conducted covered only their responsibility in the Consortium. “Texaco only agreed to take responsibility for 37.5% of contaminated sites, in accordance with its share in the oil production consortium, despite that Texaco had been the sole operator for 26 years and had designed the system responsible for 100% of the contamination in the region” (ChevronToxico, 2009, *Historic Trial*).

Despite Texaco’s agreement to treat only 37.5% of contaminated sites, they still only performed remediation efforts at 16% of the area’s they agreed to. At some sites, Texaco literally dumped fresh dirt over the polluted sites instead of actually treating the toxic soil. In some cases, Texaco used “scientific trickery” to manipulate soil samples to comply with contamination standards (ChevronToxico, 2009, *Texaco’s Fraudulent Remediation*). Texaco was given the chance to clean only a fraction of what they were responsible for, and they still performed an inadequate clean-up using extremely questionable techniques.

Also, Texaco negotiated their own standards for allowable TPH in soil that were over 50 times greater than American standards. The table below shows the standards Chevron used for maximum allowable TPHC's in soil while conducting their share of remediation (ChevronTexaco, 2009, *Texaco's Fraudulent Remediation)*. TPHC's are total petroleum hydrocarbons which are toxic pollutants formed through petroleum extraction. When compared to other allowable TPHC level's, such as those used in the United States, it is obvious how irresponsible and inflated Chevron's standards were.

Table 2: Chevron's TPHC Standards vs. Other Sources (Amazon Defense Coalition, 2009, *Case Fact Sheet*)

SOURCE	NORM TPHC/SOIL	LAW
Chevron	10,000 ppm (Criteria)	Chevron
Ecuadorian Law	1,000 ppm	Decree 1215
National Comptroller General	300 ppm	Special report on Chevron
Texas	230 ppm	Environmental Protection Agency (EPA)
Missouri	200 ppm	EPA
Arkansas	100 ppm	EPA

Despite Texaco's faulty remediation techniques, the Ecuadorian government still "signed off on a release waiving its right to seek any further compensation from Texaco for environmental damage" (ChevronToxico, 2009, *About the Trial*). Overall, Texaco spent $40 million, an insubstantial amount in comparison to the estimated $27 billion worth of damage that remains. "Chevron, which purchased Texaco in 2001, has used this release to argue that the current lawsuit is invalid, but in fact, the release only applies to claims originating from the Ecuadorian government. Private citizens, such as the 30,000 residents of the Oriente represented in the current suit, are entirely free to seek redress from the company in a court of law. No court in the U.S. or Ecuador has ever accepted Chevron's broad interpretation of the release" (ChevronToxico, 2009, Historic trial).

2.12. Site Assessment Tools

There are many tools used to assess the extent of oil contamination at polluted sites including piezometers, Shelby tubes, hollow-stemmed augers and Mostap soil samplers. Some equipment is designed to evaluate the vertical and horizontal extent of contamination while others are used specifically to monitor the flow of ground water and contaminants. Site assessment is the primary component in remediation process and the use of proper tools is pertinent.

2.12.1. Soil Sampling Equipment

Shelby tubes and Mostap soil samplers are the most common tools for testing soil samples. Shelby tubes are long, thin-walled, open-tube soil samplers that can be custom cut to fit the needs of each site. The lower end is serrated to form a cutting edge and the upper end includes holes for securing tubes to a drive head. They can also be capped to protect the sample during transportation (Humboldt, 2009). Shelby tubes are most suitable for cohesive soils with low permeability that are free from large particles, such as clay (Iden, 2007).

Another type of tool used to retrieve soil samples is the Mostap soil sampler. "The advantage of the Mostap soil sampler, compared with conventional open-tube sampling systems, is that samples can be taken at predetermined depths and no pre-drilling is necessary. The Mostap sampling system is very similar to the Shelby tubes except it uses a tube with a closed, cone-shaped end as opposed to an open end" (Iden, 2007). This design allows the tube to be drilled into the ground at specific depths to retrieve samples. It can be used to sample deeper in the ground without requiring a long pipe.

Hollow-stemmed augers are often used to collect samples deep in the soil because they have extensive drilling capabilities. These augers are hollow so that once drilling is complete, a borehole is created for sediment sampling (Geology, 2009). They are especially effective because auger extensions can be added to further the depth of drill. Hollow-stemmed augers can also be used to establish a hole for a monitoring well.

2.12.2. Water Sampling Equipment

A piezometer is a type of monitoring well designed to detect the presence of contamination in ground water or collect water elevation data to aid in determining the direction of groundwater flow (Florida State Dept., 2004). Piezometer's can be either permanent or temporary, which would most likely be the case during site assessment. These monitoring wells are constructed in different areas on contaminated sites to collect critical information regarding groundwater flow.

2.13. Remediation of Contaminated Soils

Cleaning contaminated soil is usually a lengthy and intensive process. A couple of factors determine the type of remediation technique used at a specific site. The first factor is the type of contamination that is present. Soil contamination and water contamination can require different remedial techniques. Furthermore, it is important to discern whether the problem strictly relates to surface water contamination or if the pollutants have seeped into the groundwater. Also, the weight and other physical properties of the contaminant greatly affect the technique chosen. Petroleum is a very heavy and sticky contaminant and will rule out many techniques that are used for lighter distillates such as volatilization and air stripping.

The second factor in choosing a remediation technique is the location of the contaminated site. This will greatly affect the type of remediation chosen because remediation techniques are only feasible if the site can be reached by the needed equipment. If the contaminated area is easily accessed by remediation technology, an onsite technique may be preformed. If the site is hard to reach, offsite remediation techniques must be used and the contaminants must be transported to another location.

2.13.1. Onsite Remediation Techniques

Onsite, or in situ, technologies are those that can effectively treat the contamination of soils and groundwater at the location of the contamination (Pinherio, 1995, p. 12). This allows for the contaminated medium to be treated without moving it, which may be costly and take a great amount of effort and time. The following are some prominent in situ techniques that may be usable in the remediation of the soil in northeast Ecuador.

2.13.1.1. Soil Vapor Extraction

Also known as vacuum extraction, or enhanced in situ volatilization, soil vapor extraction is an in situ technique that relies on the fact that the contaminants in the soil can volatize at temperatures found in the soil (Wong, 1997, p. 73). To volatize the contaminant, a vacuum is applied to the contaminated ground, which increases airflow throughout the soil. The vacuum blower sucks the contaminants in a gaseous form through a vapor extraction well, and sends it to a condensate separator where it is monitored by a series of pressure gauges, control valves, and flow meters. Soil Vapor Extraction methods can be easily combined with air injection, which is referred to as air sparging, or soil flushing where water and detergents are used. Figure 10 depicts a model of an SVE system

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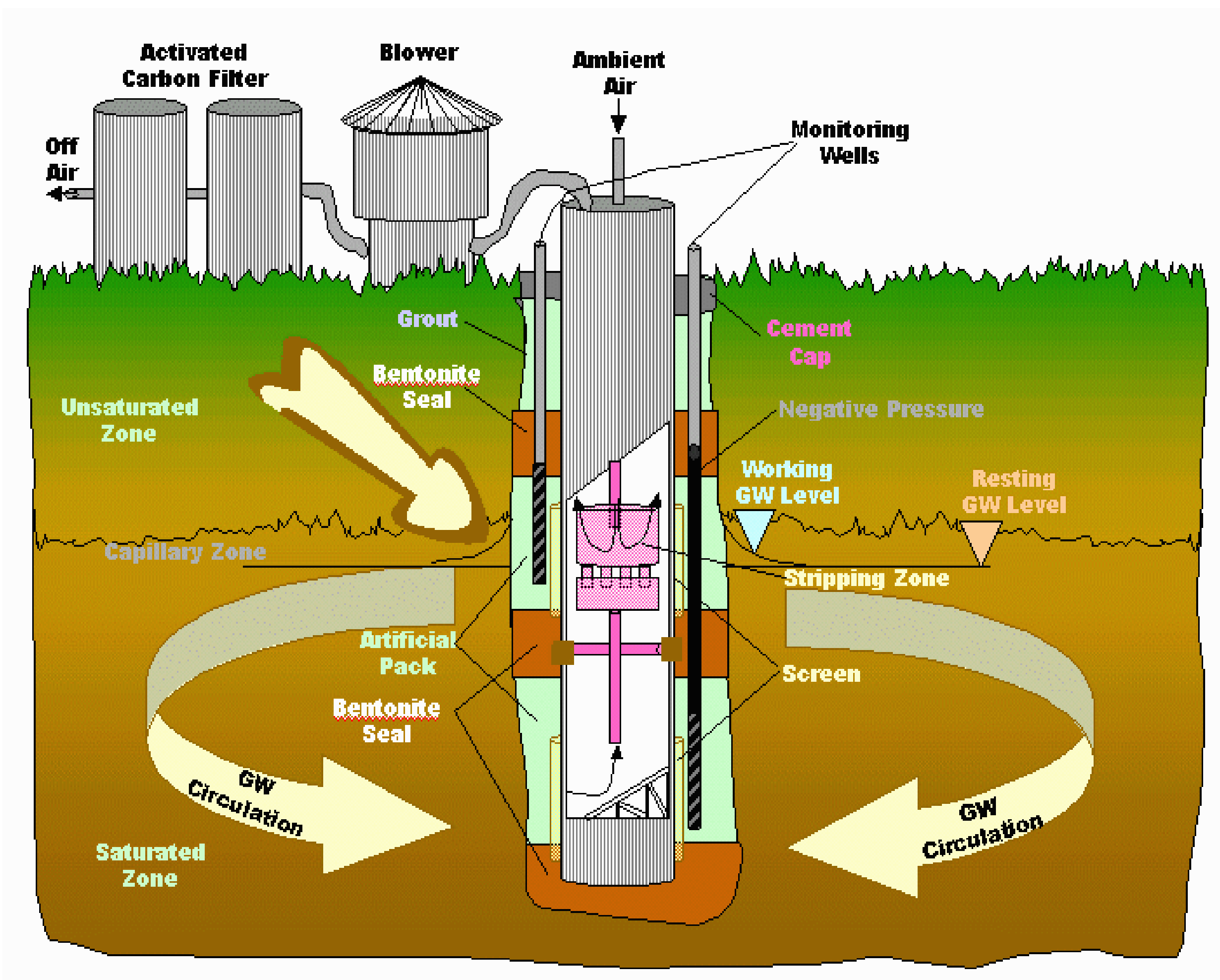

Figure 10: Soil Vapor Extraction Model (Chhetry, 2002, Fig 4.39a)

2.13.1.2. Pump and Treat Systems

Pump and treat systems used to be the most common remediation technique. This system uses groundwater pumping wells to draw contaminated groundwater to the surface. At the surface, the contaminated groundwater is treated in surface water treatment facilities (Wong, 1997, p. 191). It can then be added to the water supply or recycled back into the pump and treat system. If the recovered groundwater contains non-aqueous phased liquids, phase separation is required prior to water treatment. If light non aqueous phased liquids are present in the soil, a second pump called a product or recovery pump is added. Surface water treatment may include vapor stripping, absorption, osmosis, and bioreactors. Pump and treat systems can be effectively combined with soil vapor extraction and other in situ remediation methods. The main goals of pump and treat systems are to prevent or contain contamination migration and recovery of light non aqueous phase liquids by drawing free floating product toward the recovery wells

2.13.1.3. Degradation

There are two main types of degradation remediation. The first type is chemical degradation. During this remediation technique, chemical reagents that effectively speed up of the process of neutralizing the contaminant or transforming it into a state that is less harmful are introduced to the contaminants. Chemicals may be added to the soil to increase oxidation in metals, reduce the oxidation state of a contaminant, or cause a dechlorination reaction with the contaminant (Chambers, 1991, pp. 27-39). These procedures are very expensive and can be hard to put in place. They also may have a drastic negative impact on an ecosystem as fragile as the rain forest.

The second type of degradation remediation is biological. Related to chemical degradation, biological degradation relies on naturally occurring organic compounds that will cause the same reactions as the chemical reagents used in chemical degradation (Pinherio, 1995, p. 13). In the case of petroleum, microbial activity will transform hydrocarbons present in the soil into carbon dioxide, water and a harmless product called humus. Biological degradation is a type of bioremediation.

2.13.1.4. Bioremediation

Bioremediation, as explained by Professor Jeanine D. Plummer, Associate Professor of Civil and Environmental Engineering at Worcester Polytechnic Institute (personal communication, September 30, 2009), is an ecologically friendly alternative to some very intensive chemical remediation procedures. The injection of microorganisms that are already existent in the soil speeds up the natural remediation process. The basic principle behind bioremediation is that naturally, and over a long period of time, the ground remediates itself of almost all contaminants. Microorganisms in the soil process the contaminants and release carbon dioxide. Figure 11 outlines the different types of bioremediation.

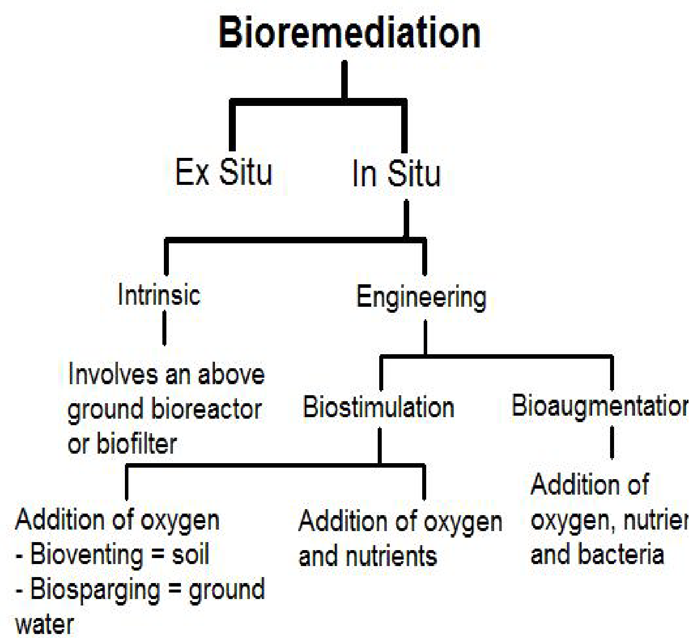

Figure 11: Outline of bioremediation techniques (Wong, 1997, p. 137)

Bioremediation takes two main steps to speed up this process (Wong, 1997, p. 138). First, a team collects soil samples to see what contaminants are present and what microorganisms are in the soil. This allows the team to focus on the specific microorganism needed for remediation. Table 3 displays the different microorganisms used in bioremediation and some of the criteria used in their selection.

Table 3: Microorganism Selection for Bioremediation (Wong, 1997, p. 141)

		Energy Source		
		Chemotrophic		Phototrophic
		Organic Source	Inorganic Source	(light source)
Source	Heterotrophic (Organic Compounds)	**Chemoheterotrophs** (Most Bacteria, Fungi, Protozoa)	N/A	**Photoheterotrophs** Few Bacteria

The second step is to inject into the soil the needed microorganism, and nutrients and supplies that it needs for survival. The microorganisms survive and decontaminate through co-metabolizing the contaminants and the injected nutrients. The microorganisms do not naturally metabolize the contaminants in the soil unless they have to. The nutrients and supplies that are injected into the soil along with the microorganisms aid in the reproduction of the microorganisms as well as allow them to thrive in the environment. This allows them to process the contaminants.

The benefit to bioremediation, and the main reason that it is so ecologically friendly, is that once the contaminants are removed, the injection of the microorganisms and the nutrients ceases and the population of the microorganisms will naturally decay to its steady state value which was present before remediation efforts. The negative side to this technology is that the effectiveness of the biological agents applied to the soil greatly depends on the status of the soil (Pinherio, 1995, p. 13). If the temperature, acidity, and oxygen level are not appropriate for microbial growth, the necessary biological reactions will not occur.

2.13.1.5. Chemical Oxidation

While bioremediation focuses on the introduction of pre-existing microorganisms to the soil, chemical oxidation focuses on injecting stable chemicals into the vadose soil layer. These chemicals usually include ozone (O_3), hydrogen peroxide (H_2O_2), hypochlorite ions, chlorine (Cl), and chlorine dioxide (ClO_2) (Chhetry, 2002, Section 4.4). The process of oxidation is one of the four main methods of chemical degradation, along with substitution, dehydrogenation, and reduction (Wong, 1997, p. 14). In an oxidation reaction, the addition of an oxygen molecule (O_2) from water (H_2O) causes the other compound in the reaction to release a hydrogen molecule and electrons as a byproduct. In chemical oxidation, one of the previously mentioned chemical agents in an aqueous form is used instead of water because of their very high electro negativity, allowing them to break down the contaminants easier.

To apply chemical oxidation to contaminated soil, injection wells must be systematically drilled to introduce the contaminants into the vadose soil layer (Chhetry, 2002, Section 4.4). Here, contaminants will be degraded before they reach the ground water layer. Site testing must be done to choose the correct oxidizing agent and delivery system. Table 4 lists the advantages and needs of each chemical agent.

Table 4: Chemical Agents and their reaction descriptions (Chhetry, 2002, Section 4.4)

Ozone (O_3)	Hydrogen Peroxide (H_2O_2)	Permanganate (Typically $KMnO_4$)
• Direct, very fast oxidation • Most effective in systems with acidic pH • Ozone is produced onsite • Delivery wells must be closely spaced • Ozone reactions can lead to oxygenation and biostimulation	• Degrades organic compounds rapidly • Most effective in systems with very acidic pH • Ineffective in systems that are moderately to strongly alkaline	• Very complex reaction • Slower reaction rates • Most efficient reactions occur in soils with pH levels of 3.5 to 12

2.13.1.6. Additional Methods

One very basic method to prevent further contamination is the implementation of containment or cutoff walls (Wong, 1997, p. 211). This concept can be seen in many tanker spills where floating barriers surround the floating oil. In soil contamination, a wall will be dug into the water table, preventing further horizontal migration. This is a very basic method and would require minimal technology. This may provide an opportunity for the incorporation of indigenous people in the remediation process. Containment walls however, are not a permanent solution. Vertical migration will continue until the walls depths are surpassed.

The technique of leaching, also known as soil flushing, is fairly simple. A harmless fluid, such as water or a detergent, is pumped into the contaminated ground. The fluid flows through the polluted soils and flush out any contaminants that are highly water soluble. When the contaminant in the soil is a petroleum based product, a surfactant is added to the flushing fluid and is used in the leaching process. Surfactants are additives that lower the surface tension of water allowing the water to spread more easily. The fluid that is used to flush out the contaminants is commonly called a leachate (Pinherio, 1995, p. 13). The leachate flows down into the water table where it will be collected in a well, pumped to the surface and emptied into a storage pond. The fluid may be treated on site, or piped to an offsite treatment facility where it can be further treated through coagulation, de-emulsification, settling and then filtration (Chambers, 1991, pp. 15-16). This technology has been tested in the laboratory as well as used in Sweden during remediation on an herbicide factory site. Unfortunately, in situ soil flushing is another technique that is dependent on high soil permeability.

2.13.2. Offsite Remediation Techniques

Offsite, or ex situ, technologies can be beneficial because they are based on the removal of the contaminant from the site through the removal of the contaminated soil (Pinherio, 1995, p. 15). Moving the contaminated soil can also be seen as a disadvantage to these types of remediation techniques because the removal of the contaminated medium can be very expensive as well as labor intensive. The contaminants along with the contaminated material are removed from the ground and treated either at a nearby facility that was built for this site, or a plant that had already existed.

2.13.2.1. Land Farming

Land farming is currently the proposed method of remediation in the Cabrera Report. Michael Cabrera used this method to estimate the cost of soil remediation in his recommendations to the current court case (Appendix N: Cabrera Report Appendix N).

Land farming is a non in situ method which requires the excavation of the contaminated soil (Riser – Roberts, 1998, p. 30 - 34). Once removed, the soil will be transported to an offsite location where it will be spread over a much larger surface area leading to a lower concentration of contaminants. Here, the soil will be tilled, agitating the contaminants and increasing oxidation in the soil. This will aid in the bioremediation that is commonly combined with land farming. Appendix N of the Cabrera Report recommends this combination. Microorganisms will be added to the soil along with their natural nutrients. The microorganisms will further decontaminate the soil. Once land farming is completed, the soil can be returned to its original location or can be used as construction back fill.

2.13.2.2. Automated Chemostat Treatment

ACT is a new process developed by BioPetroClean (BioPetroClean, 2009, ACT-Technology). It is a process meant for biological wastewater treatment of industrial sites. Automated Chemostat Treatment is very similar to in situ biodegradation and is intended to be used on the contaminated wastewater. ACT is an ex situ process that applies an appropriate bacterial mixture to the wastewater in a bioreactor. The bacteria metabolize the contaminants and multiply as the wastewater is fed into the bio reactor. The water is then passed through the system, filtered and returned back to nature. Due to the modular construction of this specific biodegradation technology, the remediation efforts can dictate the size of the facility that needs to be created.

2.14. Remediation in Ecuador

An enormous amount of pollution still remains in the northeast region of Ecuador. It is important in a time like this to recognize that the safety of a people is contingent upon the development of a successful remediation strategy. The polluted area of the rainforest struggles to maintain life and the problem will only grow as long as no solution is created. Through the analysis of the problems specific to the northeast region of Ecuador and remediation techniques that could prove useful to the remediation effort, a solution will be recognized.

3. Methodology

To accomplish our goals we compiled information from previously completed research and interviews with people of many different backgrounds and expertise. Furthermore, we made contact with indigenous people to gain insight to their experiences with development and of their views on future remediation efforts. The information we acquired was used to create a Conceptual Site Model (CSM) that depicts the problems faced, the sources of these problems, and the effects created as a result. The completion of a CSM is a method described in the *Rules of Thumb for Superfund Remedy Selection* (EPA, p.5), and created a foundation to develop recommendations for further research in addressing the problem.

3.1 Visuals

Visual representations of a situation are critical to fully understanding the problem. In many cases, this visual representation can be found through firsthand experience, but our group was unable to travel to Ecuador and witness the contamination ourselves. To remedy this, we used the videos “Crude” and “¡Justicia Now!” to create the visual experience.

The most prominent documentary we watched was “Crude.” It is a movie that was produced by Joe Berlinger in 2009 covering the judicial case between the 30,000 indigenous people of northeastern Ecuador and the Chevron oil company. We also watched a film called “¡Justicia Now!.” This video was very similar to “Crude” in its function as a public awareness piece, but “¡Justicia Now!” provided us with additional information about the Chevron litigation and more visual evidence of the pollution. These videos do not substitute direct experience, but gave us a better understanding of the problem.

3.2 Relevant Events

Andrew Miller of Amazon Watch invited us to attend the 137th session of the Inter-American Commission on Human Rights on October 28th, 2009. The IACHR hearings give an opportunity for communication between parties where human rights have been violated. Three members of the Sarayaku tribe, an indigenous tribe from Ecuador, presented their case at these hearings, and discussed their concern with projects being considered by the government that will further exploit the natural resources in the Amazon region. A major topic at these hearings is the debate on the new Ecuadorian laws concerning prior consultation. The meeting was conducted entirely in Spanish, however we were given headphones that provided English translation and allowed us to take notes. The meeting gave us more insight into the struggles of the indigenous people and the negative effects that natural resource exploitation has had on their communities. Notes from the hearings can be seen in Appendix G.

On November 5th, we attended a brown bag lunch at the Center for Justice and International Law that discussed “Indigenous Groups and Natural Resource Exploitation in Ecuador.” The primary speakers at this luncheon were the same three indigenous people that attended the IACHR hearings. They voiced their concerns involving indigenous rights and the need for an overseeing agency to promote communication with the government. After the lunch, we asked the indigenous members how their culture has changed as a result of oil development. Notes on the lunch can be seen in Appendix H.

3.3 Interviews

We identified professional contacts in the fields of biology, sanitation, environment, social relations, world economy, and oil pollution and interviewed them using question and answer and conversational styles. Interviews with these sources often led to additional contacts. Our contacts included members of environmental and human rights organizations such as Amazon Watch, the Social and Environmental Research Institute, and Stratus Consulting. We also contacted government organizations like the EPA, and non-government organizations such as the Washington Offices on Latin America. The purpose of the interviews was to supply us with analysis of the current situation in Ecuador and allow us to gain experience vicariously through people directly involved or with useful expertise.

Congressman Jim McGovern and his Legislative Director, Cindy Buhl, both visited Ecuador to witness firsthand the environmental devastation caused by Texaco. We introduced our projects to them both and interviewed them in a conversational style to learn more about their experiences and any contacts they could provide.

Another important contact we made was Tom Webler. We interviewed Dr. Webler via conference call using question and answer style. He works for the Social and Environmental Research Institute and has direct experience with the Exxon Valdez oil spill in Alaska. With this experience, Dr. Webler informed our group of the social implications that contamination can have on the people whose land has been affected. Notes on this interview can be seen in Appendix E. We were also able to engage in a discussion with Chris Herman of the Environmental Protection Agency who related to us the economic aspects of our project. Notes on this discussion with Chris Herman can be seen in Appendix F.

Stratus Consulting provides the plaintiffs of *Aguinda v. Texaco* with a technical analysis of the oil contamination. Doug Beltman of Status Consulting was our main technical contact. He acquired for us access to the Cabrera report and gave us a personal presentation that included valuable technical data and visual images.

Andrew Miller is an Environmental and Human Rights Campaigner for Amazon Watch. Through his work he has become knowledgeable of the situation in Ecuador and is in contact with many people who are directly connected to the issue. We contacted him via email and scheduled a meeting with him and several of his colleagues who were involved with different issues regarding the oil industry in Latin America and indigenous rights. He structured the meeting such that his colleagues first presented the work they had been doing and its relevance to oil development in Latin America. Afterwards, our group explained this project, and the meeting concluded with an open discussion. We learned more about the indigenous people and how they are affected by the oil industry as well as many of the ongoing problems that currently exist with the oil industry in Ecuador. He also put us in contact with Bill Powers of eTech International.

To learn information about remediation techniques and practices, we first contacted Professor Jeanine D. Plummer, Associate Professor of Civil and Environmental Engineering at Worcester Polytechnic Institute, who strongly promoted bioremediation. Notes on our interview with Professor Plummer can be seen in Appendix D. In Washington, we contacted the DC Water and Sewer Authority and were directed to Dr. Sudhir Murthy who informed us on the basic processes for water treatment.

Through Bill Powers, we were able to contact Mark Quarles, a hydrogeologist from eTech International, and conduct a discussion style phone interview. Mr. Quarles initiated the discussion on the necessity for further site assessment. As a hydrogeologist, he brought to our attention that the horizontal and vertical extent of the pollution had not yet been determined. Mr. Quarles stated that it was his opinion that recommending a remediation plan prior to full knowledge of the extent of pollution would be unprofessional and unethical. We continued contact with Mr. Quarles via e-mail where he recommended chemical oxidation as a remediation technique worth researching.

3.4 Archival Research

The main source of literature we used to analyze the current state of pollution in Ecuador was the Cabrera Report. The Cabrera Report is a technical document used during the *Aguinda v. Texaco* case, which summarizes the state of pollution in Ecuador and includes an estimated cost of total damages that have resulted from the pollution. Appendices C, F and H1 of the report relate the state of pollution in Ecuador most directly. Appendices F and H1 give a history of Texaco's operations in Ecuador and provide an inventory of all the waste pits used during oil production. Appendix N includes remediation techniques that technical experts have considered and why they are useful, particularly in Ecuador. Appendices A, D, J, and N of the Cabrera Report are included at the end of the report at Appendices K through N of our report.

Site assessment is an essential component of remediation, so we analyzed several site assessment procedures used in different areas of the world. Cases we examined included the *Florida State Regulations and Processes for Oil Contaminated Site Assessment* and a report outlining the procedure used to assess the contamination at petroleum-impacted sites in the Corrientes Region of Northern Peru, an area with geography very similar to Ecuador, called *Evaluation of the Success of Remediation Efforts at Petroleum-impacted Sites in the Corrientes Region of Ecuador*. The *Florida State Regulations and Processes for Oil Contaminated Site Assessment* document is available to the public and we accessed it via internet. This document was produced in conjunction with the EPA. Mark Quarles, an engineer for E-Tech International granted us access to the report on site assessment for the Corrientes Region of Northern Peru. The site assessment procedure used in Florida gave us insight into the strict environmental regulations of the United States, while the procedure used in Peru showed us methods that are beneficial in tropical regions. We compared the two different processes for use in further research.

We found the book *Surface Water Treatment for Communities in Developing Countries* by Christopher R. Schulz and Daniel A. Okun in the Gordon Library at Worcester Polytechnic Institute. It addresses "the proper application of water treatment technology in developing countries by advocating the design of treatment plants which are labor intensive, have low capital and recurrent costs and, by using indigenous resources, are tailored to the social and economic milieu of the region" (p.4). It provides a description of low-tech water treatment methods, instances of their use in developing regions, and cost analyses based on the requirements of the region and stated conversion rates to U.S. Dollars. We used this in analysis of the rainwater catchment system in use and the regional water treatment facility proposed by the Cabrera Report.

While in Washington, D.C. we gained access to the resources at the Library of Congress by registering for a user card in Room LM140 of the Madison Building. There we found many books pertaining to the remediation of oil contamination in soil. Two books that covered a wide range of techniques were *Remediation of Petroleum Contaminated Soils* and *Design of Remediation Systems*. *Remediation of Petroleum Contaminated Soils* detailed aspects relevant to many remediation techniques such as factors determining efficiency. *Design of Remediation Systems* covered remediation techniques, but more importantly, described in depth the necessary steps in designing a remediation system.

To address the psychological and sociological aspect of remediation that was presented in the interview with Dr. Webler and validated by the interview with indigenous people, we searched for case studies and scholarly journals using the FirstSearch database. Articles we found pertaining to the mental health effects are *Coping with Technological Disaster: An Application of the Conservation of Resources Model to the Exxon Valdez Spill* (Arata) and *Psychological Dimensions of Global Environmental Change* (Stern). The first explains the psychology of resources and presents the correlation between removal of resources and negative mental health effects by studying the mental health of commercial fisherman six years after the *Exxon Valdez* spill. This study can be found in Appendix Q. The second article does not directly pertain to the subject in question, but focuses on how people create global environmental change and how they prepare physically and psychologically when they anticipate change.

In seeking to prioritize the components of remediation identified over the course of our research, we found *A Theory on Human Motivation* by Abraham Maslow (1943). In this document, Maslow categorizes human needs in a hierarchy of complexity. In addition, he presents the psychological impact of threat upon these needs which relates the mental health component of our research. This document can be found in Appendix R.

3.5 Overall Approach

This project required multiple methods of collecting data because there are many facets to the problem. Videos provided a visual account of the contamination and the multiple dimensions of remediation that are needed. Technical data was collected through literature reviews while personal experiences and professional opinions were recorded in interviews. By combining scientific data with the expertise of people in applicable fields and the experiences of people involved with the situation, we were able to make recommendations for further research.

4. Results and Analysis

Through our research we first identified two main areas that needed to be addressed for the remediation of the oil pollution in northeast Ecuador. These areas were physical remediation of oil contaminants and psychological and sociological treatment of the affected peoples. Through further investigation we divided physical remediation into Water Treatment, Soil Treatment, and Source Removal. In addition, we discovered that site assessment is a vital component of remediation and has not been completed thoroughly enough to devise methods of addressing the other areas. There are many methods and technologies used for the assessment and remediation of a site, including both pollution and the individuals affected. We identify a variety of these and the reasons they may or may not be applicable.

4.1. Physical Remediation

Physical remediation of the oil contamination has three distinct components—Water Treatment, Soil Treatment, and Source Removal. Each component is affected by the other components and only by addressing all of them can the pollution be fully removed. Water Treatment will not likely clean all the contaminated water, but will create potable water for the people of the polluted region. Soil Treatment will allow the ecology of the rainforest to take root again in and around the drill sites and processing stations and will also prevent further seepage of pollution into the ground water. Source Removal will prevent further pollution and aid the remediation water and soil.

4.1.1. Water Treatment

As stated previously, in section 2.2 of the Background, the natural water systems are integral to the survival of indigenous peoples and the daily operation of their communities.

Treating the water for drinking, bathing, cooking, and other daily activities will not entirely clean the polluted water of the region, but will return to the affected peoples a vital resource. That being said, treatment of the water supply can occur on many scales—from large regional systems to systems that only support a single individual. For the purpose of this report we have focused only on systems that would supply large groups of people.

The most basic concept of water treatment was presented by Dr. Sudhir Murthy at the DC Waste and Sanitation Association. According to Dr. Murthy, the contaminated water will have to undergo treatment in two major categories of separation. The first category, physical separation, will enable the removal of heavy metals, drilling muds, and crude oil from the water. The second category, biological treatment, will enable the removal of organic toxins such as petroleum hydrocarbons. Further research of the processes required for removing the pollution from the natural water systems will need to be completed pending a thorough analysis of the contaminants.

The water system proposed in the Cabrera report consists of three regional systems constructed with over 400 km of piping (Cabrera, 2007, Appendix R: p.15). This system would collect water upstream from the oil pollution to minimize water purification requirements, and then distribute it throughout the contaminated area. Due to its scale, the project would take 20 years to fully implement, so Cabrera bases the amount of water output necessary on an estimated future population. The overall estimated cost for the entire regional water system is $536,696,594 (see Table 5) and includes engineering design, construction supervision, and operation and management costs for 10 years. The system would supply 40-65 gallons of potable water to each person every day.

Table 5: Cost Analysis of Cabrera's Regional Water Treatment System (Cabrera, Appendix R: Cabrera Report)

ESTIMATE OF TOTAL COSTS	Population by 2007	Projected population by 2027	Construction costs	Engineering and supervision costs (a)	Operation and maintenance costs (b)	Total estimated cost
Regional System 1	60,324	149,000	$152,846,549	$15,284,655	$18,975,564	$187,106,768
Regional System 2	63,605	157,104	$194,391,861	$19,439,186	$19,556,947	$233,387,994
Regional System 3	17,056	42,148	$80,766,007	$8,076,601	$5,244,294	$94,086,902
Downstream communities	27,900	102,170	18,098,056	2,010,448	2,006,426	$22,114,930
					Overall total amount	**$536,696,594**

In a discussion with Cindy Buhl, legislative director to Congressman Jim McGovern, we were informed of an effort between UNICEF and the Rainforest Foundation fund to create a rainwater catchment system for the polluted region in northeast Ecuador. Figure 12 is a photograph of one of the barrels. In principle, water catchment systems collect rain, and using gravity, feed the rain water through one of a variety of filters. This system has not been invasive to the environment and is easily operated and maintained by the indigenous people. There is clear room for improvement however. Doug Beltman informed us that an estimated 1,000 barrels would be required for the clean water to reach all affected communities. At the time of the project's completion by the Rainforest Foundation fund, there were only 40 barrels distributed. Nicola Peel of

Figure 12: UNICEF water catchment barrel (Perez, 2009, UNICEF)

Living Mandala, who has been working in Ecuador for 10 years, states that crystal filters were used by the Rainforest Foundation Fund, which made them more effective, but also more costly—each cost about $1,000.

After reading *Surface Water Treatment for Communities in Developing Countries* by Schulz and Okun, it became clear that there are positives and negatives to both the proposed regional system and the implemented rainwater catchment system. The book makes the statement that the defining economic and social differences between a developing country and a developed country, create the need for specialized water treatment systems. More specifically, developing countries favor "labor-intensive" systems because "a facility which can be built and operated with local labor will likely be more economical and more easily operated than a facility utilizing extensive technology" (1984, p.1).

Cabrera's proposal for a modernized regional water treatment facility would not be applicable to the polluted region of Ecuador. Schulz and Okun argue that water treatment facilities in developing countries are generally overloaded and that high-tech equipment does not withstand the overload as well as more traditional systems (1984, p.3). Because the indigenous people of Ecuador are accustomed to the ample resources provided by the Amazon River and its tributaries, we believe this assertion to be applicable. Also, high-tech operations require skilled technicians, but when citizens of developing countries are trained to operate facilities, they often leave the facility to use their new skill in a higher paying facility (p. 4). Furthermore, technologically advanced equipment would require import from developing countries. As a result, when parts break the facilities may become inoperable for long periods of time.

Another major factor to consider when reviewing Cabrera's proposal is the length of time he estimates for implementation. Twenty years is a long time to provide clean water to 140,985 people in three regions, plus almost 30,000 additional people in "downstream communities." (See Table 5 for data use in calculations). Not only does the proposed system seem inapplicable because it does not solve the very immediate lack of clean water, but he estimates the water output needed using a population count nearly 2.5 times the current population. Given that systems such as the rainwater catchment barrels are only serving the needs of 4% of the affected peoples, it seems unlikely that the population would more than double. Another way to look at the amount of potable water currently being produced is that each affected individual would receive 4% of the water they need to drink, bath, cook, and perform any other necessary operations with. As an example, Table 6 is a breakdown of household water usage in the Santa Clara region of El Salvador.

Table 6: Household Greywater Usage (Engineers Without Borders, 2006, Santa Clara Project)

Fixtures	liters/use	times/day		liters/day
washbasin	5	15	(3 times a day x 5 people)	75
Shower	100	3	(3 people (average) x 1 time each a day)	300
kitchen sink	18	3	(3 times each day)	54
laundry sink	170	1	(1 time each day)	170
Total				599
per person			**32 gal/day (120 l/day)**	
per household			**159 gal/day (600 l/day)**	

If implemented on a larger scale, the rainwater catchment system would fit the qualifications developed by Schulz and Okun. It requires no modern technology and minimal upkeep. Furthermore, with some additional research, it is feasible that much of the system could be created using locally availably materials. However, neither the catchment system, nor the regional system would aid in the remediation of the water systems that are already polluted. This is economically sound but to completely remediate the polluted environment an effort will need to be made to clean the contaminated water systems.

We developed another potential track of research for water treatment using the positive attributes of the regional and rainwater catchment system and the guidelines created by Schulz and Okun. This third path of research would evaluate the applicability of low-tech community scaled facilities. Smaller scale water treatment facilities would take only enough water from the rivers and streams for one indigenous community to use. This would be a positive method of water treatment because the facilities could be tailored to the resources and geography that are local. Also, the lesser amount of infrastructure that would be required to pipe the water where it is needed would cut down on implementation time, upkeep, and costs. Furthermore, the community scaled facilities could be developed in phases to allow for the gradual increase in available clean water, and would aid the remediation of the polluted environment by cleaning contaminated water.

Unfortunately there are some negatives to the smaller system. One negative is the number of facilities that would need to be built to facilitate all the affected communities. An approximate number of these facilities is unknown and would fluctuate depending on their scale and the number of local villages. Another negative about this system is that it is for the most part unstudied. Creating a system of small, locally applicable water treatment facilities would require an ambitious amount of research and involvement from experts of the region. Lastly, it is unlikely that the organic pollution within the water will be removable without the application of some chemical additive. This additive would likely need to be imported. Overall, a community based system has many advantages over the regional system and the catchment system but would still be more invasive than the catchment system.

To estimate a cost for community scaled water treatment, the closest comparison we could make was to a project being implemented by Engineers Without Borders (EWB) in Santa Clara, El Salvador ("Santa Clara, El Salvador Water Distribution and Public Health Project", 2007). The water treatment system EWB proposes would supply approximately 260 households with 160 gallons of potable water daily (52 gallons per person). The system is relatively basic and relies on a 380-foot well to collect and provide the water. The water is then pumped to a storage/treatment tank that is at an elevation higher than the homes that it is providing the water for. Since the storage tank is at higher elevation, the water is piped to the individual homes using gravity as a natural force to propel the water. This minimizes the use of pumps which results in lower operation costs. They estimated that total price to construct the system would be $300,000, which includes cost of materials and labor, and also an additional $23,000 annually for operation cost (only $90/household). Figure 13 shows the schematic of the EBW's water treatment system, a relatively basic yet effective plan.

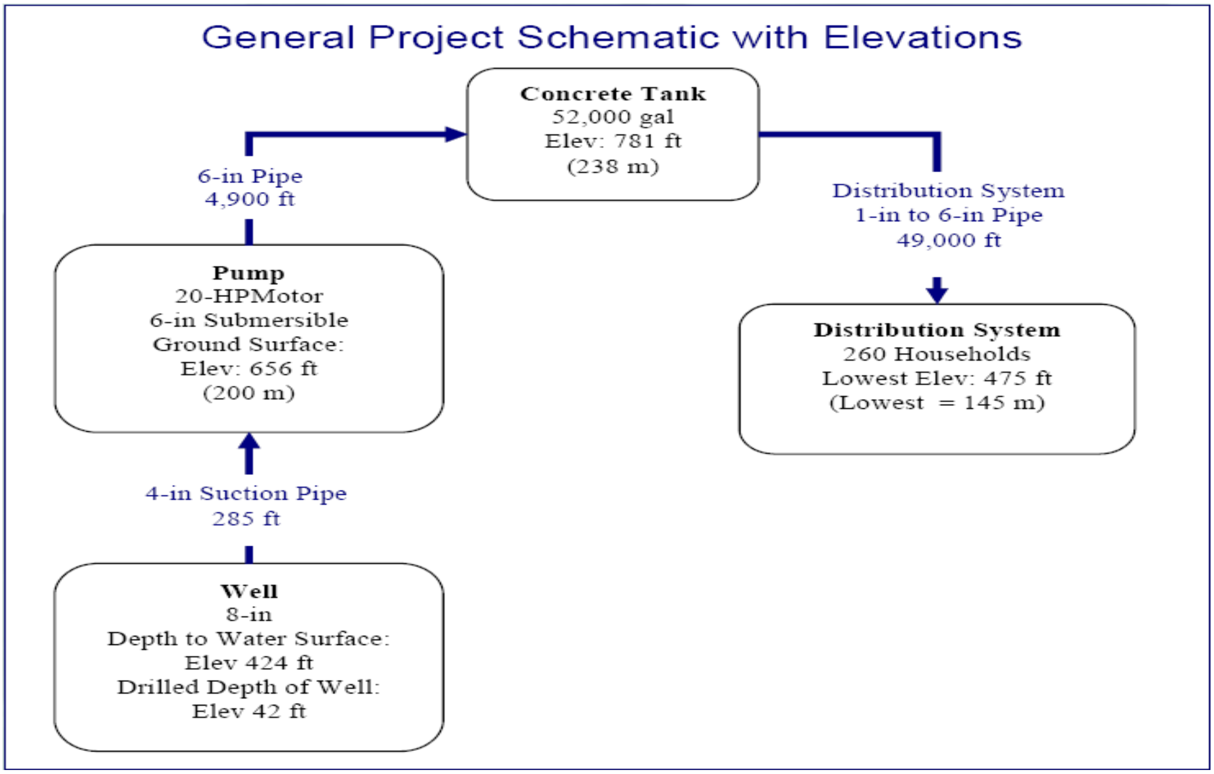

Figure 13: General Description of EWB water treatment system (Engineers Without Borders, 2006, Santa Clara Project)

This project has been of particular interest to us because it is a great example of a locally-applicable water treatment system, an idea we believe would be beneficial in Ecuador. Although there are many variables between the El Salvador project and the water treatment project in Ecuador—the number of facilities, the type of pollutants, and local ecology—we have focused our attention on the main similarities. The overall approach of the two projects is the same: provide clean drinking water on a local scale as inexpensively yet effectively as possible. A water treatment and supply system like EWB's provides sufficient amount of water to drink and wash with and is relatively easy to construct in comparison to more advanced technologies.

4.1.2. Soil Remediation

To stop further contamination of the water table and to allow the environment to return to its natural state, the soil must be remediated. According to Appendix N of the Cabrera Report, over 3,788,000 cubic meters of soil must be remediated throughout Texaco's concessions (p. 3). However, given the low number of sampled sites, 93, used to evaluate the pollution and the fact that many of the soil samples contained pollution at the bottom of the sample, we believe that the volume of polluted soil could be much greater. That being said, using the information we have, we have investigated a variety of different soil remediation methods that could prove applicable.

4.1.2.1. Advantages and Disadvantages of Viable Remediation Techniques

The first technique we would like to address is land farming, the method of remediation proposed by the Cabrera Report. The main advantage of land farming is that it has been used repeatedly with positive results (Cabrera, 2007,Appendix ___: p. 7). Appendix N of the Cabrera Report lists projects that have taken place in Florida, Alaska, Colorado, Washington, Missouri and Texas that have all used this form or remediation. Although the cost of excavating the soil makes this remediation technique quite expensive, removing the contaminated soil quickly stops further contamination of surrounding areas.

Land farming is also a very basic and direct remediation technique. With less technology involved, there is an opportunity to incorporate indigenous people in the remediation process. Also, Cabrera proposes the incorporation of bioremediation into the land farming method, which is a much more environmentally conscious procedure than other methods including incineration or vitrification of the contaminants.

The major down side of land farming is that it is a non in situ technology, meaning the soil must be removed to treat it. The removal of a large amount of contaminated soil in the Amazon Rainforest would be very invasive to the environment. The Amazon Rainforest is a sensitive ecosystem and the massive excavation of soil may disrupt a very delicate balance. Also, the equipment needed to excavate such a large quantity of land will require a much more substantial vehicular infrastructure because of the weight and size of the equipment trucks. Soil extraction is also very labor intensive and will require a large amount of time, money and man power. Mark Quarles granted us access to a report detailing another disadvantage of this technique. In his report, *Evaluation of the Success of Remediation Efforts at Petroleum-impacted Sites in the Corrientes Region of Ecuador (2009, p. 47)*, Mr. Quarles examined the effectiveness of the offsite bioremediation done in the region. He stated that the clay content and high soil moisture levels made the biodegradation ineffective.

We learned of bioremediation through an interview with Professor Jeannine Plummer of Worcester Polytechnic Institute. A benefit of bioremediation is that when decontamination is complete, injections of nutrients and oxygen cease and the population of microorganisms reacclimatizes to the soil and returns to natural levels (Riser – Roberts, 1998, p. 102). Another benefit of bioremediation is that it is very effective at removing benzene, which Doug Beltman of Stratus Consulting says is the contaminant in soil that needs remediating the most. Bioremediation is also affective at removing light petroleum hydrocarbons. Figure 14 shows how bioremediation degrades contaminants and releases carbon dioxide.

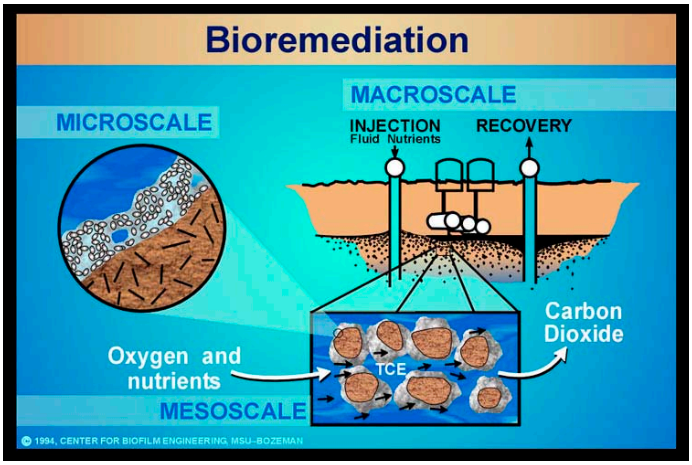

Figure 14: Basic bioremediation Process (Dirckx, 2007, MSU)

The drawback of in situ bioremediation is that its effectiveness is highly dependent on soil and contaminant characteristics. The factors affecting bioremediation include the natural supply of macro- and micronutrients, the availability of electron separators, the presence of capable bacteria, and subsurface geologic characteristics (Wong, 1997, p. 138). Bioremediation is highly dependent on high permeability in the soil to transport the nutrients and oxygen throughout the contaminated area. Clay's low permeability of about $10^{-15} – 10^{-19}$ m^2 limits the effectiveness of in situ bioremediation. The type of contaminants present also affects the bioremediation process. Although lighter, more soluble petroleum hydrocarbons are more biodegradable, a compound's resistance to bioremediation increases with the molecular weight of the contaminant.

Design of Remediation Systems introduced our group to Soil vapor extraction. Soil vapor extraction is a relatively low cost remediation method when compared to excavation or incineration (Wong, 1997, p. 75). The low instillation costs can be attributed to the fact that the technology required to perform soil vapor extraction is readily available and easily constructed. Figure 15 shows the instillation of a soil vapor extraction system. Soil vapor extraction can be used on hydrocarbons and other light weight contaminants that are easily volatilized. This method aids in preventing further groundwater contamination because it reduces the contamination found in the vadose layer directly above the water table. The most important benefit of soil vapor extraction is that it has been previously employed to treat large areas of contamination and is known to create minimal site disturbance.

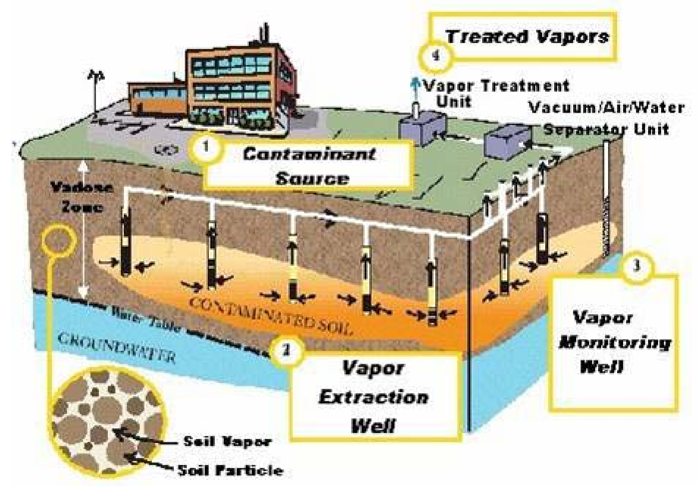

Figure 15: Soil Vapor Extraction System Diagram (Marketplace Lists, 2009)

Unfortunately, the effectiveness of soil vapor extraction is highly dependent on the permeability of the soil being decontaminated. To treat a large area of contamination, the soil must be very permeable like gravel. The soil commonly found in the Amazon Rainforest has high clay content below a thin layer of dense decomposing organic matter that makes up the forest floor. Both of these soil characteristics combine to make the radius of influence of each vapor extraction 20 feet or less (Wong, 1997, p. 75). As a result, a very high number of wells would need to be dug, which would add to costs and labor. Furthermore, heavy weight contaminants like heavy metals are highly resistant to soil vapor extraction, and, as in most remediation methods, a power source would be required. Electricity may not be easily obtained so a gasoline generator may be necessary.

In *Design of Remediation Systems*, Wong et al state, "Despite some criticisms of pump and treat in the literature, it is still a useful treatment method, especially where there is a significant amount of free product to be recovered." (p. 192). Due to successful implementation in many past remediation cases, pump and treat systems have been proven effective. Their combination with other in situ technologies may lead to a great increase in efficiency.

The main reasons that experts have moved away from pump and treat systems are primarily based on efficiency (Wong, 1997, p. 192). These systems can take a while to reach the expected remediation goals. They are very effective when the concentration of contaminants is high. However, as decontamination continues and the level of contamination drops, pump and treat system become less efficient due to the volume of water needed to be pumped to remove a certain amount of contaminant. Finally, the permeability of the clay in rainforest soil would further decrease the effectiveness of pump and treat technologies.

Chemical oxidation was first suggested to our group through correspondence with Mark Quarles of eTech International. Chemical oxidation may prove applicable to northeast Ecuador. Figure 16 shows how a system may be installed. Chemical oxidation is very effective in soils with high pH levels (Chhetry, 2002, Section 4.4). The Amazon Rainforest naturally has acidic soils due to the decomposing plant matter that lies on the surface. The chemicals used in drilling and oil production are also very acidic.

Depending on soil conditions, different chemicals can be used in chemical oxidation, but the process is generally characterized by rapid reaction rates and efficient degradation of aromatic hydrocarbons. Section 4.4 of the *Remediation Technologies and Screening Guide* states that "In general the oxidants have been capable of achieving high treatment efficiencies (*e.g.*, > 90 percent) for unsaturated aliphatic (*e.g.*, trichloroethylene [TCE]) and aromatic compounds (*e.g.*, benzene), with very fast reaction rates (90 percent destruction in minutes)."

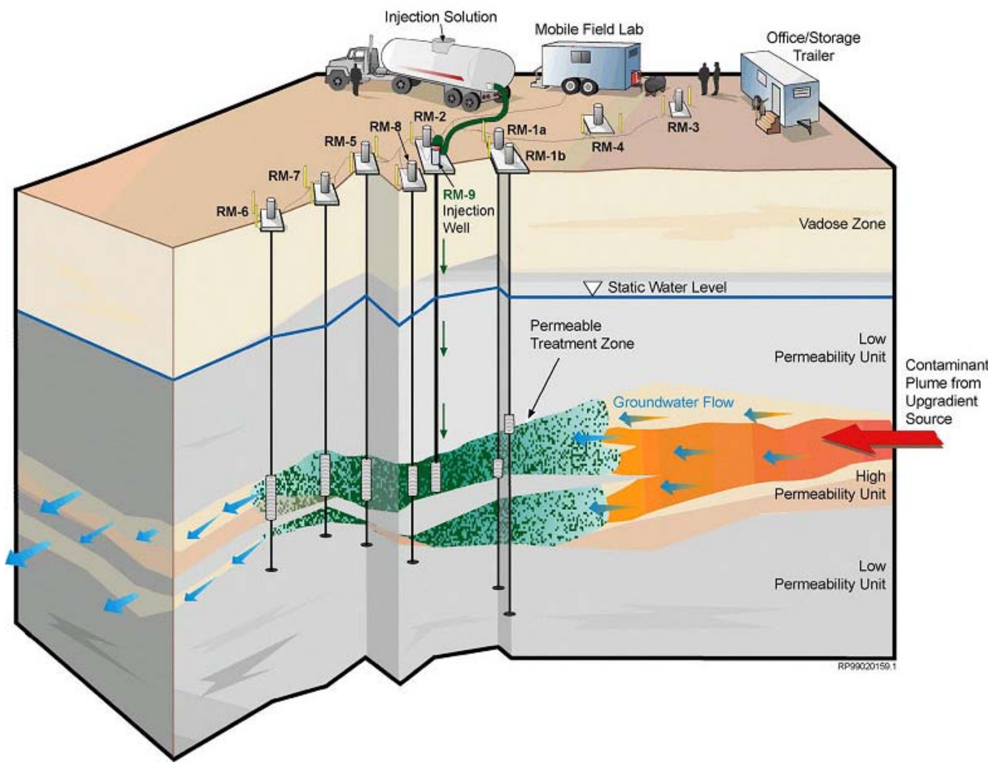

Figure16: Chemical oxidation system design and processes (Stewart, 2008, TAMU)

As well as being very destructive to the contaminants in the soil, if the process is not carefully monitored, chemical oxidation may also prove highly destructive to the environment. In addition the chemicals used must be transported in high quantities, potentially requiring upgrades to the road infrastructure of the contaminated region.

In order to completely spread the contaminants using chemical oxidation, a systematic drilling of wells will be required to spread the chemicals (Chhetry, 2002, Section 4.4). Based on our research of the Exxon Valdez disaster, we are hesitant to recommend adding further chemicals to the soil in the Amazon Rainforest. However, Mark Quarles personally recommended chemical oxidation as a possible remediation technique. We stress that if chemical oxidation is to be considered, extensive soil sampling and testing must be done. We also recommended that it first be tested and monitored in a very small area before implementation on a larger scale.

We first learned about phytoremediation in *Design of Remediation Systems.* Phytoremediation is a relatively new technology but uses very environmentally conscious methods. In the phytoremediation process, plants that are native to the region and can survive in the contaminated soil are identified and then used to remove pollution (Wong, 1997, p. 215). Phytoremediation relies on two benefits of plant root systems in soil. First, as plants extract nutrients from the soil, they will also extract contaminants in the soil through phytoextraction. Phytoremediation has been used in soils containing heavy metals and after phytoextraction has occurred, the plants were harvested for the heavy metals. Second, phytoremediation functions as a way to enhance in situ and natural bioremediation by increasing oxidation in the soil. Figure 17 shows the many ways which phytoremediation can be beneficial.

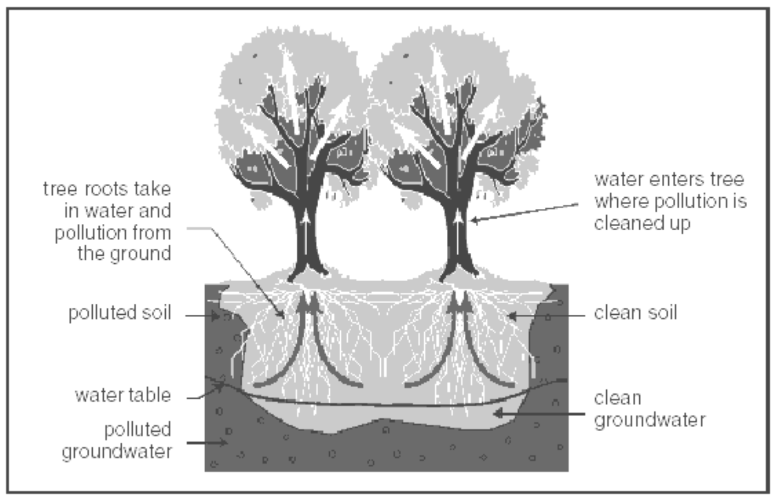

Figure 17: Processes involved in phytoremediation (Stewart, 2008, TAMU)

The main downside to phytoremediation is that its effectiveness is limited to the extent of the plant root system. In Mark Quarles' report, *Evaluation of the Success of Remediation Efforts at Petroleum-impacted Sites in the Corrientes Region of Ecuador* (2009, p. 49), Mr. Quarles describes phytoremediation as unsuccessful. Although it was not the main remediation technique, it was used as a supplementary technique to ex situ bioremediation. He stated that without the removal of chlorides in the soil, reforestation, or phytoremediation would be impossible. Simple grasses would be the extent of surviving plant life.

4.1.2.2. Cost Analysis of Applicable Soil Remediation Techniques

Many factors go into the estimation and cost analysis of remediation processes. These factors are very closely connected to the factors which obstruct remediation and its effectiveness. Other factors that must be considered when estimating the cost of a remediation technique include labor costs, equipment transport, training expenses, and various taxes and licensing fees. Labor in Ecuador will be significantly cheaper than labor costs in the United States of America. However, this reduction in cost will be offset by increases in the cost of importing and transporting equipment to the site and training Ecuadorian laborers to operate the equipment. Labor costs may increase if previously trained workers are used but training costs will decrease.

Cost estimates usually give a range to allow for fluctuation in the factors stated. To compensate for the impermeable clay soil, the extent of the pollution, and any unforeseen factors, we have determined our cost analysis based on the maximum values for each remediation method. To obtain these cost estimates, we referred to the Federal Remediation Technologies Roundtable's *Remediation Technologies Screening Matrix and Reference Guide, Version 4.0*. In Appendix N of the Cabrera Report, Richard Cabrera uses an average cost determined by land farming case studies. He based his final cost of $1.852 billion on an average of $489 per cubic meter. We believe that a higher value must be used to account for the identified factors and for the development of an offsite treatment facility. The maximum value that Richard Cabrera records is $1,078 per cubic meter, taking place in Cantonment, Florida. With this estimate, the total remediation cost would be nearly $4.1 billion. Table 7 compares the estimated costs of the researched remediation techniques.

Table 7: Cost Estimates for Researched Remediation Techniques (Chhetry, 2002)

Remediation Technique	Cost per cubic meter	Total cost (assuming 3,788,000 cubic meter of contamination)
Land Farming (Proposed)	$489.00	$1,852,332,000
Land Farming (Maximum)	$1,078.00	$4,083,464,000
Bioremediation	$100.00	$378,800,000
Soil Vapor Extraction	$975.00	$3,693,300,000
Phytoremediation	$483.00	$1,829,604,000
Pump and Treat	$35.31	$133,771,957
Chemical Oxidation	N/A	N/A

The Federal Remediation Technologies Roundtable (FRTR) estimates that bioremediation could cost as little as $100 per cubic meter, totaling $378 million, however many additional operations will need to supplement bioremediation, adding to its cost. Pump and treat systems will cost only $133 million but will require supplementary processes as well. Phytoremediation could cost over $1.8 billion if done properly with sufficient monitoring, but may have little impact, and soil vapor extraction may cost upwards of $3.7 billion at $975 per cubic meter. A sufficient cost analysis of chemical oxidation could not be found due to the variables involved. More detailed expense breakdowns for Soil Vapor Extraction and Phytoremediation can be found in Appendices O and P and more information on Cabrera's cost assessment can be seen in Appendix N.

4.1.2.3. Proposal for Soil Remediation

We believe bioremediation is the most promising remediation technique because it is environmentally safe and minimally invasive. However, bioremediation is negatively impacted by clay, so it would require the aid of other techniques. The technique we propose for research in this area is soil vapor extraction. When used in combination, this process might increase the ease of migration for bioremediation.

Additionally, we propose research in the applicability of phytoremediation. Phytoremediation is primarily limited by the need for a plant that not only can survive in the contaminated soil, but can also remediate the soil and process the contaminants. It is also severely limited by size of the root system. Research should be conducted, looking into the existence of a plant that is naturally occurring in the Amazon Rainforest, can survive on the contaminated land, is able to process the contaminants founds on the surface layers of the soil, and has a root system large enough to have a significant impact on the level of contamination in the soils. This technique might be successful in dealing with surface contamination which would compliment a combination of soil vapor extraction and bioremediation to focus on deeper contamination. These ideas would benefit from greater research of the Amazon's geology, and if it is possible to remediate above and below the clay layer of the soil, making the impermeability of the clay avoidable entirely.

4.1.3 Pipeline Considerations

Ecuador has an intricate pipeline system that is thousands of miles long called the Trans-Ecuadorian pipeline (see Figure 18). Jose Luis de la Bastida of the Inter-American Development Bank informed us that the pipeline has spilled 450,000 gallons of crude oil since its construction over 30 years ago (see Appendix J). Over the years improvements have been made to the Trans-Ecuadorian pipeline, which has resulted in decreasing the frequency of spills. Even though the spills don't occur as often, it is still a major issue since any additional contamination directly affects the remediation process. The only way to entirely clean up the pollution is to prevent the problem from occurring and remediate what has already been contaminated.

Figure 18: An example of the pipelines running through Ecuador (Doug Beltman, Stratus Consulting)

Originally, the problem with the pipeline was poor construction. However, over the years modern technology has been used to fix many of its construction flaws. Currently, the majority of breaks are caused by earthquakes since Ecuador lies on a fault line. The most recent break in the pipeline occurred in 2006, and released 14,000 gallons of contaminants. Our contacts at IDB have urged us to be cognizant of the fact that the problem is now mainly due to natural issues and that pipeline engineering expertise is required to address this problem properly. Therefore, while pipeline breaks are an ongoing problem, the pipeline's re-engineering is not an area in which we can provide great assistance.

4.2 Psychological and Sociological Impacts

With respect to mental health impacts, the situation in Ecuador is very similar to what resulted of the Exxon Valdez catastrophe in Alaska. Dr. Thomas Webler informed us that, despite the differences in the two events of environmental disaster, many of the psychological impacts are similar. *Coping with Technological Disaster: An Application of the Conservation of Resources Model to the Exxon Valdez Oil Spill* explains the correlation between environmental catastrophes and mental health impacts through a study on commercial fisherman affected by the Exxon Valdez oil spill (Arata et al, 2000, p.23). According to the study stressors result from threats on the mechanisms by which we obtain and retain the things we value (p.24). These mechanisms are called resources and can include possessions, personal characteristics, and social systems. People in the affected region of Alaska in many ways define themselves by the fishing industry and the social community that it creates (p.26). By shutting down the fishing industry, the oil spill threatened their means of maintaining that community and self definition and their economic stability.

Arata et al states also states that because technological disasters are anthropogenic, or caused by humans, relief from the mental health effects often includes litigation (Arata et al, 2000, p.24). As a result, the time span of the effects may directly correspond to the length of the court case. At the brown bag lunch presentation by indigenous Ecuadorians, we learned that oil development and subsequent pollution forced many people to abandon their architecture and style of dress. Also affected was their food security, the availability of vital natural resources, and their means of economic survival. Oil development not only threatened their "resources" but also the values those resources protected.

More research would need to be done to create a plan that would reverse the mental health effects faced by the indigenous people in the polluted region, but this effort would be aided through the return of resources, both physical and psychological. We believe that the remediation of physical pollution will facilitate that return, but also that the physical remediation plan should not be created without the help of the affected individuals. This idea of involvement is supported by ideas represented in *Psychological Dimensions of Global Environmental Change* by Paul C. Stern. According to Stern's report, when people anticipate major changes to their environment, they prepare through mitigation or adaptation (1992, p. 288). The indigenous people to not have the opportunity to prepare n these ways, so having knowledge of the remediation plan and a role in its implementation may allow the individuals to prepare for the imminent changes. Furthermore, this preparation may remove stresses that resulted from the initial changes.

4.3 Site Assessment

Mark Quarles made it clear to us that we need a better understanding of the extent of the contamination in Ecuador to develop an effective remediation design. When he made this statement, he was referring to the soil contamination, but we have come to realize that a complete site assessment would include an evaluation of the contamination in all physical senses—water, soil, and sources—and of the effects that contamination has on the peoples residing within the polluted region.

The type of remediation technique(s) applicable to the physical remediation will depend upon factors that vary from site to site. Therefore, it is essential to identify these factors at each site and only then develop a remediation plan. The information necessary for site assessment includes the vertical and horizontal extent of contamination, rate and direction of groundwater flow, degree of surface water exposure, rate and direction of contamination flow through soil, the geologic characteristics that influence migration of contamination, and the location of contamination in relation to human contact (Petroleum Contaminated Site Cleanup Criteria, Chapter 62.770.600). Since many of these factors have not been adequately assessed at the sites in Ecuador, it would be professionally irresponsible to recommend methods of remediating the water, soil, and sources.

A Conceptual Site Model (CSM) is a method of risk assessment outlined by the EPA in *Rules of Thumb for Superfund Remedy Selection* (EPA, 1997, p 5) Included in a CSM are the sources of contamination, the methods with which contaminants travel, who and what is exposed to the contamination, how they are exposed to the contamination, and what the effects of exposure are. The site model is a three-dimensional look at a situation and creating one allows for the formulation of a remediation technique evaluation system. This may prove effective in incorporating all of the aspects of the problem into one visual representation. An example of a similar model can be seen in Figure 19, a flow diagram developed in the Cabrera Report, though it may be more effective to include pictures that identify with each of the steps.

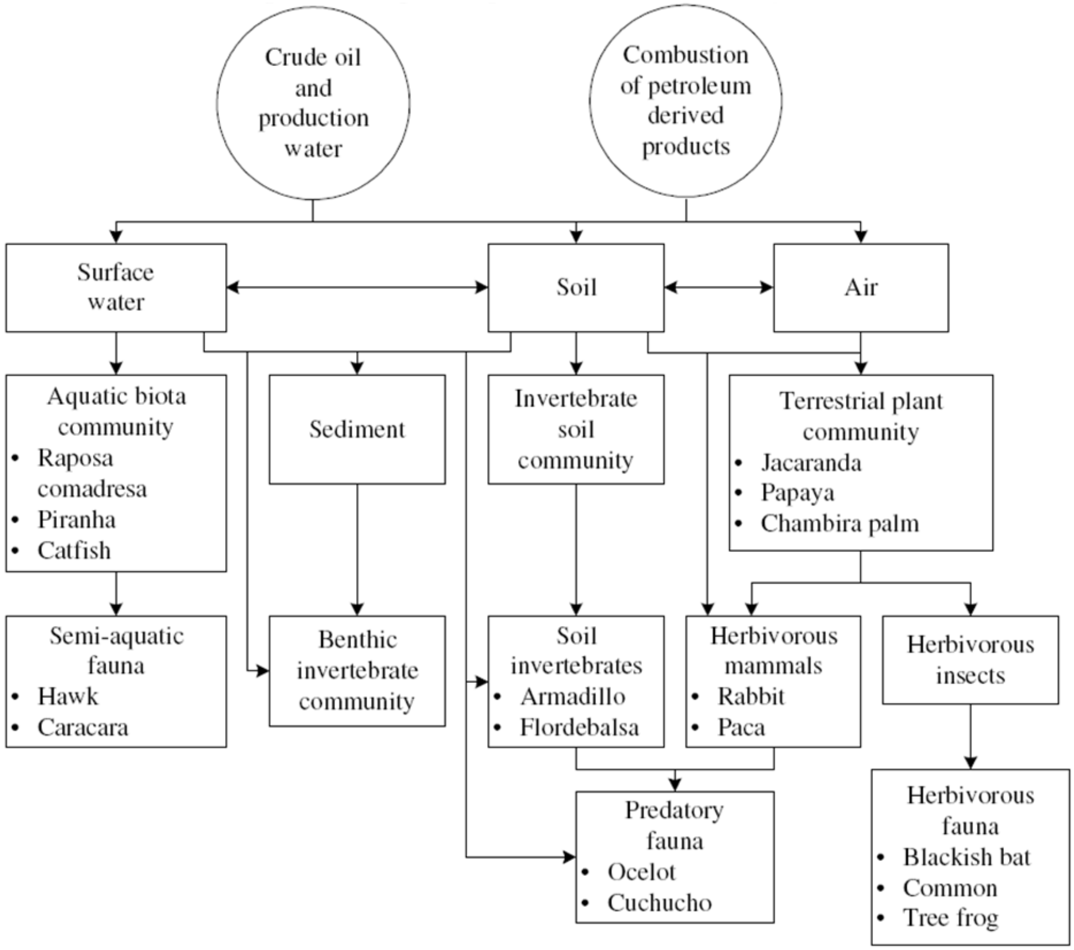

Figure 19: Conceptual model identifying potential sources of contamination, exposure routes, and ecological receptors in the concession area. Listed ecological receptors are only small representation of the total diversity found in the Amazon ecological region. (Figure 1 of Appendix J of the Cabrera Report)

To sample for the extent of the soil pollution, geophysical equipment such as hollow stemmed augers or Shelby tubes help in determining the extent of pollution (Petroleum Contaminated Site Cleanup Criteria, Chapter 62.770.600). They dig into the ground at designated points of the contaminated sites and retrieve samples of soil at different depths. These samples are tested for contamination and since the depth of the tested soil is known, they provide a three dimensional map of the level of contamination at different depths and where the contamination ends.

Contaminant migration due to water transportation must also be addressed. The state of Florida recommends the "Use of monitoring wells, piezometers, or other sampling and measurement techniques to obtain the migration of petroleum products' contaminants of concern below the water table, of groundwater flow, and of relevant hydrologic parameters" (Petroleum Contaminated Site Cleanup Criteria, Chapter 62.770.600). Figure 20 demonstrates the structure of a piezometer. The principle behind a piezometric well is that the elevation of the water level in the pipe directly correlates to the piezometric pressure in the ground. Monitoring wells such as piezometers, allow researchers to more accurately track the hydro-migration of the contaminants.

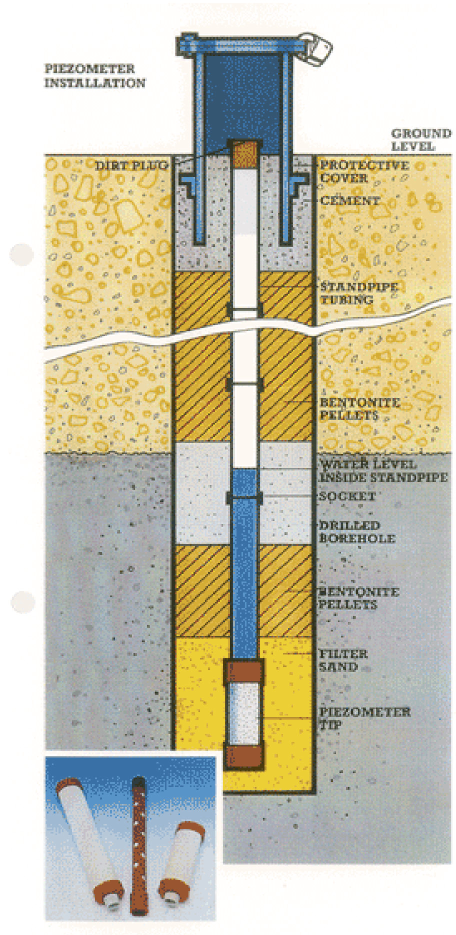

Figure 20: Piezometer Construction (Stuart Well Services Ltd., 2009, *Geotechnical Materials – Piezometers*)

There are several techniques for obtaining accurate water samples in rivers and streams. Two of the devices used are Niskin Bottles and semipermeable membrane devices (SPMD). Each device collects undisturbed river water data which can be analyzed for contamination. A Niskin bottle is a cylindrical, closed-ended device attached to a winch which is lowered to a predetermined depth in the water and then opened to collect the sample. The sample is then taken to a lab to identify the exact type and level of contamination (Great Lakes, 2009). Unlike the Niskin bottles that capture “instant” samples of contaminated water, semipermeable membrane devices collect water contamination over an extended period of time, sometimes up to a month (Chapman, 2009). They are set in place in the designated water system and their semi-permeability allows water to flow through while capturing the contaminants.

The SPMD method is often more effective than “instant” water samples for two reasons. First, contamination is generally present at very low concentrations in waterways because of the dispersion caused by the large volume of water. Second, the concentrations of contaminants at a given site can change drastically because of water’s unpredictable flow. The extended period of exposure involved in the implementation of an SPMD allows us to calculate an average amount of contamination at each test site. In many cases, and SPMD can be used to replace multiple “instant” water samples. However, it may be necessary to determine both short term and long term effects of contact with contaminated water, so we believe the use of both methods would be best.

The most important aspect to source assessment is identifying the source. Because the sources of pollution—the unlined waste pits and pipeline breaks due to earthquakes—are already identified, further assessment is unnecessary. Methods of psychological assessment are detailed in *Coping with Technological Disaster: An Application of the Conservation of Resources Model to the Exxon Valdez Oil Spill*. See Appendix Q for more information.

4.4 Site Prioritization

After sufficient site assessment has been completed, prioritization of contaminated sites must take place. The Environmental Protection Clinic of Yale University lists many possibilities for a governing agency in site prioritization (Angélica Afanador et al, p 15). One option is the use of a preexisting national institution or agency, either foreign or domestic. This may be the most efficient method; however, the needs of the indigenous people may be neglected.

Another option is the creation of a local organization consisting of leaders of the affected communities. This would seem ideal but may slow the decision making process. The final option which we feel is the best compromise is a combination of the first two ideas. An organization would be created consisting of environmental officials and local leaders. Officials included may represent governmental agencies, universities, foreign organizations, or consulting firms. Combining the public and private sector would allow the board to keep everyone's best interests in mind.

After an organization is given the ability to prioritize the sites, a prioritization list must be created. Each processing station and well site would need to be considered for remediation, totaling 378 different sites. After consulting with many remediation specialists and NGO's we have created a list that will help identify the sites with the most environmental and social impacts.

Site Impact Check List:

1. Level of contamination
    a. TPH Levels
2. Proximity to nearest population
    a. Water source
    b. Community
    c. Farmland
3. Rate of contaminant migration
    a. Surface water
        i. Distance from nearest river
    b. Groundwater
        i. Ease of contaminant migration to the water table
    a. Proximity
4. Ease of access by remediation equipment
    a. Roads
    b. Surface conditions
5. Physical size of Contaminated Site
    a. Surface area
    b. Volume

Information pertaining to the site characteristics of samples sites and some definitions of contamination levels at those sites can be seen in Appendix K: Cabrera Report Appendix A. When further information is collected, the prioritization list above could aid in analyzing this data.

4.5 Components and Prioritization

We believe there are Five Components of Remediation and have identified the initiating, or Primary Component, as Pollution Assessment. Pollution Assessment is followed by Four Ancillary Components: Water Treatment, Source Removal, Soil Treatment, and Minimization of Psychological and Sociological Impacts. All four components are interrelated, and therefore would be most effective if addressed concurrently. We acknowledge that a lack of adequate resources may prevent this and thus have prioritized the ancillary components using the hierarchy of needs devised by Abraham Maslow (1943, PsychClassics). According to this theory the most basic needs must be addressed and satisfied before addressing more complex needs.

Water Treatment is prioritized as the first ancillary component of remediation because it is a basic physiological need. This component is followed by Source Removal because removal of the contaminants will aid the remediation of both water and soil but will not have an immediate effect on the basic needs of the affected peoples, nor will it be as extensive or complex as soil remediation. The third ancillary component of remediation, Soil Treatment, addresses the need for security (1943, PsychClassics). It is the most complex physical remediation component, but its major effect on people is through its impact on the ecology of their environment and not through direct contact. The remediation of soil addresses the need for security because the people will not feel safe eating crops or hunting animals until they are sure contaminants are no longer polluting the ecology of their community. The final ancillary component of remediation is Minimization of Psychological and Sociological Impacts. This component is considered the most complex of the ancillary components because it is not as easily or directly remediated as physical and security needs. According to Maslow, needs of security are of higher order than basic physical needs, and psychological needs are of higher order than security (1943, PsychClassics). Until the lowest order is addressed, the next highest order will not be acknowledged as an issue.

5. Conclusion

There are Five Components of Remediation. Pollution Assessment is the Primary Component and has not been completed comprehensively for the oil contamination left by Texaco in northeast Ecuador or the effects of that pollution. Therefore, it would be unethical to recommend an exact remediation solution at this time. The assessment required for Ecuador can be broken into soil assessment, water assessment, and psychological and sociological assessment of the affected indigenous peoples.

For soil assessment, we propose further research into the combined use of hollow stemmed augers and Shelby tubes to determine the horizontal extent and absolute depth of the pollution at each site. It is imperative that samples be taken extending past what is believed to be the horizontal extent of the pollution to ensure all dimensions are fully covered. To determine the direction and rate of groundwater and sediment flow at each pit site, we suggest research into the use of piezometers. In addition, monitoring wells may be implemented to help map hydro-geologic characteristics.

For the assessment of surface water pollution, we propose the combined use of Niskin Bottles and semipermeable membrane devices (SPMD). Niskin Bottles will present data for research into the short term effects of exposure to contaminated water. SPMD's will present an average calculation of contamination by collecting pollution over a longer period of time. Surveys would be the primary method of assessing the mental health impacts of the contamination. Though arduous, a proper pollution assessment will allow for the most effective remediation.

Following Pollution Assessment are Four Ancillary Components of remediation. The components are Water Treatment, Source Removal, Soil Treatment, and Minimization of Psychological and Sociological Impacts. If necessary, they should be prioritized in the order they are listed but would ideally be addressed concurrently. Water Treatment is the most pressing ancillary component. We believe that the most applicable and least invasive method of creating clean water would be the development of community based facilities. These facilities would be constructed almost entirely of local materials, using foreign supplies only where absolutely necessary. Ideally, they would also be sustainable by the indigenous people, so they could eventually continue their ways of life without the assistance or interference of outside sources.

The second ancillary component, Source Removal, consists of two separate problems. The first is the susceptibility of the Trans-Ecuadorian Pipeline to break due to earthquakes. The pipelines once leaked because of faulty construction, but have since been improved. It will be necessary that a geophysicist address this issue. The second and more extensive source of pollution is the formation water and other contaminants found in waste pits. It is necessary to drain these pits and transport the contents to an offsite location for treatment. Removing the sources of pollution will aid the remediation of water and soil.

Soil Treatment, the third ancillary component will be the most extensive remediation process. We have discovered through research of remediation techniques used in the past, and of those available today, that further research must be done in the field of in situ techniques. This style of remediation could prove the most useful in Ecuador pending a greater knowledge of its capabilities. Of the in situ techniques, we believe bioremediation is the most promising because it is environmentally safe and minimally invasive. That being said, we propose using soil vapor extraction to increase the permeability of the clay, and phytoremediation to aid the cleaning of the top soil. These three techniques would combine to address multiple dimensions of the soil pollution.

The final ancillary component of remediation is the Minimization of Psychological and Sociological Impacts. Further research will be needed to identify the best way to heal the psychological and sociological damage created by Texaco's oil development. However, we believe that involvement in planning the physical remediation process, as well as the implementation of that plan, will be included in any plan to heal psychological or sociological damage. It is important to return to the indigenous people the things they value and the mechanisms they utilize for protection of those values.

It is our intention that this paper will be used to create more specific projects as identified by the Five Components of Remediation. Further research of these paths will only be possible with the involvement of many organizations. Non-governmental organizations (NGO's) such as Amazon Watch and the Amazon Defense Coalition can help raise awareness and develop connections and resources in Ecuador. These organizations can also aid in fundraising, which will be necessary to continue work in remediation research.

Continued interaction with Congressman McGovern will help create further connections both in the United States and outside the country. Also, as the co-chair of the Tom Lantos Human Rights Commission, he will have the opportunity to address the public in relation to the problem. Increased awareness of the general public and involvement from both the non-profit and private sectors, will facilitate the development of future projects addressing the contamination.

As development progresses, technical assistance will be necessary to create the most applicable and effective remediation system. Stratus Consulting, the firm that provides technical data and assistance to the plaintiffs in the *Aguinda v Chevron* court case, will be essential in providing detailed site data. Remediation analysis would benefit from the involvement of eTech International, an environmental consulting firm that has advised us in remediation techniques. More specifically, Mark Quarles , a hydrogeologist may prove to be a very valuable resource. In addition, the Federal Remediation Technologies Roundtable (FRTR) could be very helpful in providing specific remediation details. Lastly, in order to address the human impacts of remediation, an organization like the Social and Environmental Research Institute may provide assistance in assessing, monitoring, and counteracting psychological and sociological damages to the effected indigenous people. These organizations each provide a valuable function, and the remediation effort will be addressed most effectively if all the functions are represented in its development and implementation.

Glossary

Aguinda v. Texaco – Lawsuit between 30,000 indigenous people of the northeast region of Ecuador against Chevron, the oil company who currently owns Texaco. The plaintiffs are suing Chevron for the devastation they caused to both the environment and the health of the people. The lawsuit was filed in 1992 and is still pending in Ecuador.

Automated Chemostat Treatment (ACT) **–** wastewater treatment technique in which an appropriate bacterial mixture is combined with contaminated water to metabolize and treat it

Bioremediation – ecologically friendly remediation technique that involves injecting naturally-occurring microorganisms into contaminated soil to counteract the pollutants

Cabrera Report – professional report composed by a court-appointed expert which includes potential remediation plans as well as cost estimates for the remediation, water treatment, and health impacts

Clay – type of soil with very low permeability; it is the most significant layer of soil in the Amazon and has caused many problems in finding an effective soil remediation plan

Cofàn – an indigenous tribe who has inhabited the northeast region of Ecuador for centuries; they have been greatly impacted by the pollution caused by oil exploration in the area

Concession – an area of land granted by a government to an individual or company; Texaco was granted a concession in 1964 of over 1 million hectares to perform oil operations

Consortium – a partnership between financial institutions for carrying into effect some financial operation requiring large resources of capital; Texaco was part of a consortium with PetroEcuador to fund the oil operations in Ecuador, however Texaco was the sole operator at the time

Degradation - remediation technique used to treat contamination; there are two different types: chemical and biological

Ex-situ – "off-site" typically referring to remediation techniques performed at a site different from the area of contamination

Formation water – combination of underground water and drilling water that contains corrosive pollutants which results during oil drilling

Hollow-stemmed augers – commonly used drill used to set groundwater monitoring wells

In-situ – "on-site" typically referring to remediation techniques performed at the site of contamination

Land farming – remediation technique where the contaminated soil is removed and spread over a large area of uncontaminated land; reduces the concentration of contamination so it can treated more effectively

Leaching – remediation technique which involves pumping a fluid into the contaminated soil and flushing out the contaminants

Mostap soil samplers – soil sampling equipment used during pollution assessment

Oil extraction – The removal of oil from underground reservoir by use of a drilling rig. Substances such as wastewater, drilling muds, and natural gas are usually mixed with the oil during its extraction and require separation at a processing station.

Oil reservoir – volume of untouched oil beneath the earth's surface

Petroleum hydrocarbon – term used to denote a large family of several hundred chemical compounds that originally come from crude oil

Permeability – the capability of soil sediment to permit the flow of fluids through its pore spaces

PetroEcuador – Ecuadorian state-owned oil company who took over 100% of Texaco's oil production equipment in 1992

Piezometer – temporary or permanent monitoring well used to collect water-level elevation data which helps in determining the rate and flow of groundwater and contaminants

Production Water – see formation water

Pump and treat systems – remediation technique in which ground water containing contaminants is pumped of through wells and treated on the surface

Quichua – an indigenous tribe who has inhabited the northeast region of Ecuador for centuries; they have been greatly impacted by the pollution caused by oil exploration in the area

Refineries – industrial processing plant where crude oil is refined into more useful petroleum products using heating

Shelby tube – soil sampling tool used to collect soil for testing purposes

Siona-Secoya – an indigenous tribe who has inhabited the northeast region of Ecuador for centuries; they have been greatly impacted by the pollution caused by oil exploration in the area

Soil Vapor Extraction – also known as vacuum extraction, is a remediation technique that involves using wells to vacuum the gaseous forms of contaminants and through a series of pressures gauges and condensers it is treated

Total Petroleum Hydrocarbon (TPH) – term used to refer to the amount of petroleum hydrocarbons in a soil sample, generally in ppm

Wastewater – see formation water

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APPENDIX

APPENDIX A: REVIEW OF SIONA-SECOYA TRIBE

The Siona-Secoya indigenous tribe of northeastern Amazonia resides primarily in Ecuador (Vickers, 1996). They are a tribe with ancient history but since their land has been devastated by oil pollution, their culture has been greatly disrupted. The Siona-Secoya is one of the smallest indigenous tribes of the region with a population of only 347 indigenous peoples in Ecuador during 1980.

Originally, the Siona and the Secoya were two separate tribes but they shared very similar cultures and both spoke with a variation or the Tucano language family (Becker, 1999). Due to their drastic similarities, they eventually merged into one group during the 20^{th} century, the Siona-Secoya. However, some members have recognized the advantages of maintaining their distinct ethnic identities and still consider the two tribes as separate entities.

Before the oil industry entered Ecuador in the 1960's, the Siona-Secoya resided peacefully in the Amazonian rainforest. Their settlements were semi-permanent and were generally established along major rivers or secondary streams (Vickers, 1996). Although they didn't technically own the land they lived on, they had inhabited it for hundreds of years without much resistance. Their way of life consisted of maintaining small farms that produced enough food to feed the village and small time fishing and hunting on the side.

However, when oil production began in Ecuador, the Siona-Secoya's land was right in the middle of the oil companies operations. Like many of the river-dwelling tribes of the area, the Siona-Secoya were been forced to relocate as a result of the polluted environment. In rare cases, some members of the Siona-Secoya actually took jobs working for Texaco since they had no other options (Vickers, 1996). However, they have mostly all been forced deeper into the Amazon since there settlements have basically been destroyed by oil production.

APPENDIX B: REVIEW OF QUICHUA TRIBE

The people of the Quichua tribe have inhabited Ecuador for thousands of years and many still remain there today. The Quichua is the largest indigenous group in all of South America with a total population of 2.5 million people, 20% of which reside in Ecuador (Joshua Project, 2009). They are a tribe of rich culture and a unique customs, however, the Quichua's way of life has been severely interrupted and damaged throughout history.

Originally, the Quichuas were a mountain-dwelling tribe that survived off farming and hunting. They used advanced agriculture techniques including systematic irrigation and mountain terracing (Joshua Project, 2009). The Quichua "empire" consisted of great temples, canals and mountain roads that stretched over a thousand miles from Cuzco to Quito. The people of the community worked cohesively in order to maintain a self-sustainable way of life (Joshua Project, 2009). They survived using this system of living for hundreds of year, maybe even thousands, until the Spanish conquistadores invaded their land.

During the 1500's, Spanish conquistadores invaded South America and aggressively took over the land. The Quichua of Ecuador were forced to into the Amazon Basin and had to adapt their way of life to surviving in the jungle. Millions died from both the drastic shift in lifestyle and from the diseases brought by the European conquerors (Jamison, 2008). It has taken them hundreds of years to adapt to life in the jungle, but presently over 550,000 Quichua live in the Ecuadorian rainforest (Joshua Project, 2009). They build their homes along rivers, which serve as means of transportation, toilet and bathwater, and a source of food and drinking water (Joshua Project, 2009). They also use small farms and livestock to provide food for the community. After finally adapting to their new way of life, once again an outside force has disrupted their lifestyle.

The introduction of oil production to the Ecuadorian Amazon has had a drastic impact on the Quichua. The pollution that has resulted from oil production has infected the rivers and soils, making them toxic and unusable. The rivers that the Quichua are so dependent on now contain oil contamination and their "river-dwelling" lifestyle is no longer an option. Many members of the Quichua community have moved deeper into the Amazon to avoid the pollution. However, thousands have already died or are suffering serious illnesses caused by the pollution (ChevronToxico, Affected Communities). The Quichua people have once again been forced to adapt to a new way of life because an intruder has plundered their land.

APPENDIX C: REVIEW OF COFAN TRIBE

The Cofán people are another one of the major tribes affected by oil production in the northeastern Amazon region of Ecuador. The Cofán originated from migrant hunters who crossed over what is now the Columbian border (Nación Cofán del Ecuador, "Who are we?"). Historically, the Cofán lived in separate villages that functioned independently unless one is threatened by an outside source at which time they unite. They traded and hunted as their main sources of survival along with subsistence farming. They often traded tools made of stone, which they were highly skill at crafting.

The outside influences on Cofán society did not begin with Texaco. Major Spanish influence began in the 1560's (Nación Cofán del Ecuador, "Who are we?"). The Cofán were a warrior people and resisted Spanish influence heavily by burning down the foreign settlers villages. In 1602 a mission just outside of Cofán territory began influencing Cofán tendencies. They became more peaceful; however, when the Cofán began feeling threatened they retaliated and drowned the mission's priest. Following this, they were left alone however the damage had already been done. Although they could avoid the ideals of the missionaries, the Cofán were unable to avoid the diseases the foreign colonists brought with them. Small pox, measles, polio, whooping cough, cholera, tuberculosis, and malaria spread rapidly through Cofán territories. Over about 40 years, the Cofán population dwindled from anywhere between fifteen and fifty thousand down to a few hundred. The Spanish settlers that originally came in contact with the Cofán described them as a strong, proud, and vast people. The Cofán had a relatively high level of technology in terms of indigenous groups but due to white influence changed to a more basic people concerned more with simple survival. By the time the first oil company arrived to take advantage of the natural resources in the late 1940's, the Cofán people numbered a mere 500 and were located around the local rivers. At this time the Cofán didn't feel very threatened.

In 1964, Texaco arrived in the Amazon Rainforest on a scale that dwarfed that of Shell Oil Company, the previous oil prospecting company (Nación Cofán del Ecuador, "Who are we?"). Missionaries that had been helping the Cofán with much needed medicinal care, petitioned the government for tribal land reservations in 1965 but were denied. Company workers taunted Cofán men for their traditional dress which consisted of beads and necklaces and Cofán women were harassed and raped. Alcohol and robbery became common in Cofán lands. In 1966, Texaco drilled its first oil well and with it the began a seemingly unceasing amount of oil pollution. This was made evident by the dead fish floating in the contaminated streams which the Cofán used for survival. The main road from Quito was built in 1972 and with it thousands of colonists who were given 125 acres of what the government considered unused jungle. This unused jungle was originally Cofán hunting territory but the government mandated that the new owners of this land clear a percentage of the forest for farming. In 1977 the Cofán finally reach an agreement with the government that gave them the rights to 20,000 acres however it consisted of minimal river shore and was only a fraction of what they used to live on.

Some Cofán resorted to ecotourism to create a livelihood, moving down river to less polluted areas however even this new territory was threatened when the government included it in a wildlife reserve, infringing on the rules and uses of the land (Nación Cofán del Ecuador, "Who are we?"). All of this was done without consent from the Cofán people.

The resilient Cofán people began resorting to their native warrior instincts and resisted further exploitation of their land. They arrested workers that were sent to build a helicopter pad and the workers were extracted by the company the next day. This received national media attention as the Cofán refused to negotiate with the companies. The companies met the Cofán demands of much higher restrictions and finished their studies in that area. Texaco came in with much more force, carrying with them weapons as well as their tools. Reacting to this, 20 armed Cofán warriors forced workers off the well sites and burned the platforms, considered one of the proudest moments in Cofán history. Currently the Cofán are predominantly economically invested in conservation projects to guard their land and the rainforest. They continue to hunt, fish and farm for survival. The influences of oil production have lead the Cofán to a discovery of their identity, pride in their history and traditions, and their culture remains strong and resilient yet they are now apprehensive of outside aid.

APPENDIX D: INTERVIEW WITH PROFESSOR PLUMMER

Ecuador Remediation Group
<u>Professor Plummer Interview Minutes</u> **<u>September 30th, 2009</u>**
Location: Kaven Hall 106
Attendees: Johnson, Professor Plummer
Format: Personal Interview
Start: 11:30AM

1. Ground remediation will differ between surface and subsurface
2. Subsurface Remediation
    a. Pump and Treat
        i. Oil may stick to soil
        ii. Could take decades
        iii. Costly
    b. **Bio-Remediation**
        i. Environmentally friendly
            1. Very important in the rainforest
        ii. Basic process is the injection of microorganisms into the soil that will digest the oil (i.e. bacteria, algae, ect.)
        iii. Co-metabolism
            1. The microorganisms will not naturally digest the oil so basic nutrients for the microorganisms will need to be pumped into the soil and they will digest both
        iv. The microorganisms will die off after the remediation efforts are finished and nutrients are no longer pumped in
    c. Soil vapor extraction
        i. Used in removing volatile gas
3. Surface Remediation
    a. Exxon Valdez
    b. Reverse osmosis for waste water
        i. Water is pumped through a very fine poured filter
        ii. Very energy intensive so very costly
        iii. Leaves you with very concentrated contaminants to be dealt with
    c. Distillation
        i. Not applicable due to mass of contaminated product to be dealt with
4. Movement of Contaminant
    a. Hard in soil because it sticks to the soil
    b. Very high toxicity
    c. Oil properties make it difficult

   d. Will be hard to create remediation facilities on site so pipelines may be best way to move the contaminated product and contaminants
5. Problems that may have been overlooked
   a. Remediation won't be a one step problem
      i. Multiple technologies will be necessary
      ii. Phases
         1. Emergency
         2. Middle
         3. Residual
            a. A country like Ecuador may not get to this step before saying the cleanup has been adequate
6. Oil is a Non Aqueous Phased Liquid
   a. Light and Dense

Adjourn: 12:00PM

APPENDIX E: INTERVIEW WITH DR. THOMAS WEBLER

Ecuador Remediation Group
Dr. Thomas Webler Interview Minutes **October 28th, 2009**
Location: Smith Group
Attendees: Oil Development and Remediation Teams
Format: Conference Call
Start: 10:00AM

Are you familiar with any of the activities, jobs, etc. indigenous groups in the northeast of Ecuador are involved? What is the main way of life?

- "Way of life" doesn't have direct firs hand experience, only knowledge from presentations and other literature.
- Understands rural development communities
- Lived in India for 4 months and worked there: similar way of life, poverty

How far away from indigenous people should oil operations take place?

- Residential areas: people have a right to not have life interrupted. Oil operations near people would disrupt life
  - Inability to raise livestock
  - Agriculture
  - Family.
- In such regulations need flexibility for regulators to be adjustable
  - 100 or 1000 meters and you could throw these numbers around but most would need to be reviewed by government
    - Look at power lines and telephone lines regulations too
- He would throw out a .5-1 km; you need a regulation to make oil development feasible and not impossible

What agencies are known to help establish communication between indigenous groups, governments, and fossil fuel companies?

- He is not sure of what organizations that are working in that area. The organizations need both experience and respect. Need to decide if these organizations are going to play a role via dialogue.
- NGOs
- Las Liannas

How do you suggest indigenous communities organize themselves so that the interests of their members are taken into consideration, as opposed to just the opinion of one or two community leaders?

- Worldbank: communications
- COMGAP: has publications out
- Reconstruction and development: European world bank (wanted public involvement, and know how to go about it)
- What turns out to be important is consistency and commitment of people and agencies involved.
  - Must see process through the end.
  - And that the same individuals must attend these processes (the whole course).
  - Must make sure government sends the same people back.
  - These are more successful when the same people come to all meetings.
  - You don't want to give everyone the right to prevent companies to do what they can't and should be doing legally.

Where in the world have you seen the least amount of environmental and social disaster as a result of oil production?

- He will email more articles and information.

Alaska, what are the social effects and what not after a number of years?

- Been terrible, talk about the 3 effects:
  - 1) Economic: Cordova, fishermen when fish died lost income
  - 2) Psychological: Trauma and depression with the groups. Leads to:
    - Suicide
    - Unhealthy relations
    - No willingness to live
    - Psychologists have been developing and performing surveys on the people and discovering the trauma being caused by the lawsuits and actual impact and spills. The avg. level of trauma (Post traumatic stress disorder) = the level that would be the same as a year after a person has been raped.
    - Alters friendship and relationships and institution of the society: WORK
  - 3) Cultural: Because of the spill contaminated the ecology they couldn't hunt seals or fish not allowed to harvest even after it was cleaned it, the fact that

they were so saddened and depress because of the damage of the wildlife they have developed fear and trauma.

- A generation of the tribe (late teens early 20s) lost the skills of the people

- Would love to see studies based on Ecuador and the effects on the people
- Human impact assessment: being developed to address human rights violation and people are saying if you perform a big problem you need to assess the effects on the humans it will affect. Based upon public health considerations and rights. (done before project); congress waved doing environmental impact assessments for Alaska spill
- Social impact assessment: economic based
- After the spill they do periodic (shoreline surveys) and assess the severity of the damage and the progress of the clean up.
- University of Mississippi, University of Southern Alabama both got funding from NSF and performed a study on psychological stress. And perform surveys there will leave for Alaska next week

How are communities organizing the indigenous people? What is your opinion so everyone's concern is heard?

- Sounds like a good point
- ON the right way
- The more the community can do aka present a united front the better
- Getting communities together to talk about common interests and goals

Are US laws and standards applicable to international communities and regions?

- US laws are generally good environmentally
- Resource recovery act
- Use US laws as an outline then reform them to be applicable to the region or country your focused on, "What do we need to tweak to make effective here"

Many people say that the US laws cannot be applicable. For example: $26-30 billion annual put towards regulations, but if taken from the US to the other countries, the country may not be able to pay for this.

- To see if these laws work, the must media do investigation and follow up on companies that may fail to follow the law. Media as a watchdog. We also have a court system in the states and a legal precedence, and it's meshed with the regulations. Very different from Peru and Ecuador.

APPENDIX F: INTERVIEW WITH CHRIS HERMAN

Ecuador Remediation Group
Chris Herman Interview Minutes **October 30th, 2009**
Location: Office of International Affairs (EPA)
Attendees: Chris Herman, Oil Development and Remediation Teams
Format: Open Discussion
Start: 3:00PM

- Look into NGO's and other organizations involved specifically with Ecuador issue to gain better understanding of problem
- EITI is a result of the effort to reduce environmental impacts
- Indigenous people are sick and tired of people telling them what will make them better, they want to see solution implemented
- Superfund for Ecuador
  - Allow superfund for Ecuador: we are going to go ahead and remediate and/but hold you accountable for the anything that occurs
  - Possible create a procedure that involves agreements between the government and the indigenous people
- INECE – an EPA supported initiative
  - The gap is that they have laws but they are not enforced
  - Enforcement side likely underfunded
- U.S. Trade Representative's Office
  - One thing that is happening is making the trade agreements argue mental development
  - If we have free trade agreement with Ecuador we could provide some environmental capacity for them
- Suggestions for further research
  - Organize meeting with IADB – many people involved with issue in Ecuador
  - Trans-Ecuadorian pipeline and pollution issues that have occurred from it
  - Oil spill in France – not exactly a similar case study because of different climate but still good to research similar issues
  - Find contact at Quito university to help provide more firsthand information

APPENDIX G: INTER-AMERICAN COMMISSION ON HUMAN RIGHTS
137TH PERIOD OF SESSIONS

Ecuador Remediation Group
IACHR Hearing Notes **November 3rd, 2009**
Location: General Secretariat Building of the Organization of American States
Attendees: Oil Development and Remediation Teams
Format: Hearing Session
Start: 4:15PM

Petitioners begin the hearing:
Rights of indigenous peoples

- Article 69 of the new constitution
    - Right to prior informed consent
    - Right to life in relation to land
    - Right to property
    - 24 rights included
- Regulation on prior consultation in respect that there was no consultation with indigenous people
- Prior consultation is not possible since it is given after the right to oil is given
- Indigenous people were not consulted prior to the passing of the recent mining law
- No prior consultation to carry forward the law
- Ignorance of the people that decide to avoid contact

Indigenous people of coast, highlands, and Amazonia

- Concerned that even after approving the constitution there are laws the delegitimize that constitution
- Very concerned with decrees on the mining law that have no regard for the indigenous people and their lands
- State is supporting the catholic missions and opening roads and settlements that infringe upon the lands of the indigenous people
- Concerned with the development model because his territories are threatened
- 5 large projects in the indigenous lands
    - Effects on biodiversity
    - Environment and community
    - Mining industry calls the projects “open skies”
- 14 nationalities, 28 indigenous groups
- Needs help in communication with the republic of Ecuador
- Want to establish a dialog mechanism to have communication between the indigenous and the republic

  - Uncertainty-development model of state carries no guarantee for future indigenous children's lives
- Blocks 23 and 24 have not yet been examined but were reopened
- Indigenous people demand to have oversight. They want to be respected and considered citizens. They want to be countries of Ecuador.
  - They want oversight in discussions about rights with Indigenous peoples to guarantee human rights and a report on those rights

Representatives of the state respond:

- Agrees that there should be a way to institutionalize dialog permanently between the two sides
- State has prepared a bill that hopes to create a legal body where citizens can approach if their rights have been violated
- A few days ago in Quito, the law was enacted changing the organic law on the mining law
  - The bill for water resources in a short while will become a national law
  - This shows how the nation is open to the indigenous people
- The national government is under transition from the prior councils
  - They attempt to have the legal administrative power to design and implement everything concerning the indigenous people in Ecuador
- Progress made in the case:
  - Withdrawing the explosives – the gov. has signed two agreements and have finished the first stage
  - The police are currently extracting the bentolite
  - The community is overseeing this process
  - Third stage planed for December
  - Last stage to be completed in December as well
  - The gov have reached an agreement to identify those who are in most danger and are given an id card which they can use to call and there will be an immediate response
- Ecuador says that there will be no agreements with oil companies on oil production until complete provisions are met
- Meetings are being held to get them out of block 23 (this is not near our project, more in central part of the country)

Commissioner for indigenous people's rights

- What is your evaluation of the process of incorporating observation of Conai on the impact of the laws on water?
  - Petitioners

  - The Ecuadorian state had missed the op to give an explanation of the indigenous rights of the people.
  - Flip flop of the state on the use of block 23 and 24

Adjourn: 5:15 PM

APPENDIX H: INDIGENOUS GROUPS AND NATURAL RESOURCE EXPLOITATION IN ECUADOR

Ecuador Remediation Group

IGNREE Brown Bag Notes **November 5th, 2009**

Location: Center for Justice and International Law (CEJIL)

Attendees: Marlon Santi, President, Confederation of Indigenous Nationalities of Ecuador (CONAIE); Patricia Gualinga, Leader of the Sarayaku Indigenous Group; Hólger Cisneros, President of the Sarayaku Indigenous Group; Mario Melo, Ecuadorian Attorney; Oil Development and Remediation Teams

Format: Brown Bag Lunch

- The speakers pursue a constitution that embraces plurality and respects the rights of indigenous communities.
- Speakers express the urgent need for an international overseeing organization that guarantees the processes that should occur in dialogue.
- There are 5 mayor projects pertaining to the category "grand scale mining projects".
    - The government does not want to start dialogue on these topics.
- 90 percent of the rivers in the Ecuadorian Amazon are contaminated as a result of these types of projects the government supports without the consent or pre-consultation of the indigenous communities.
- In the year 2002, Compania General de Combustibles (CGC) entered Sarayaku territory without consent.
- The Ecuadorian government has been trying to put indigenous leaders in jail.
- Who's to blame?
    - The economical model established in Ecuador.
    - There is no framework in the Ecuadorian constitution to counteract climate change.
- 3 indigenous communities have disappeared in Ecuador as a result of these mining projects.
- In 2006, oil companies bribed indigenous leaders, Napo is one of the communities affected by this.
- There are 5 dialogue tables in the process so far.
- Complains for no consultation or previous consent from the indigenous communities.
- The companies have become a substitute for the state.

APPENDIX I: MEETING AT ECUADORIAN EMBASSY

Ecuador Remediation Group
Professor Plummer Interview Minutes **November 18th, 2009**
Location: Ecuador Embassy
Attendees: Isabel Albornoz, Paul Moreno, Oil Development and Remediation Teams
Format: Open Discussion
Start: 4:00PM

- National Development Plan
    - Includes many environmental protection/reforestation details
        - Eventually reach 30% of land mass under protection of Ecuador government (currently 18%)
        - Treat 100% of pits contaminated with oil
        - Implement clean technology throughout Amazon region
            - Solar
            - Wind energy
            - Electric vehicles
        - 12 top priorities - #4 being to promote clean/safe environment and safe drinking water
        - Forest restoration over an area of 150,000 hectares
    - Funding to be provided by foreign governments as well as the Ecuadorian govt.
        - Seeking $315M over next 13 years to help support the national development plan
        - Germany has agreed to supply $50M over 13 years
        - Spain has agreed to supply $20M in first year and based on their investment decide whether they'd like to continue supporting the project
        - Not seeking assistance from United States due to the fragility of our economy
- Ecuadorian government's relationship with indigenous people
    - Trying to establish better dialogue with the indigenous people
        - If they are forced to relocate then govt. wants to provide guarantees to support them
        - Leadership of indigenous people in Ecuador are very positive towards new president
    - Some indigenous groups are willing to work with government while others refuse
- Plans for future oil development in Ecuador
    - Government needs to establish transparency and accountability between government, investors, and people

  - Very expensive to enhance the technologies of oil exploration but they are considering using horizontal drilling as well as increase use of helicopters in order to reduce the number of drill sites and number of roads to access those sites
- Government does not willingly seek foreign assistance because they want to prove themselves as a strong developing country and develop their own capacity
  - Willing to accept it but would prefer to continue government strength
  - Most important to correct the oil exploration procedures on their own

APPENDIX J: MEETING AT INTER-AMERICAN DEVELOPMENT BANK

Ecuador Remediation Group

IADB Meeting Minutes **November 20th, 2009**

Location: IADB

Attendees: Luz Melody, Jose Luiz, Oil Development and Remediation Teams

Start: 3:30PM

- Problems related to pipelines
    - There are spills caused by pipeline breakdowns but generally caused by earthquakes so not something we should focus on
    - Geotechnical equipment may need to be researched but far beyond extent of our project
- Changes being made by PetroEcuador
    - Originally wells required 2 hectares of land but now using horizontal drilling you can produce 10 wells worth of oil while using only one horizontal well
    - Reduces risk of oil pollution
- IADB involvement with oil pollution
    - presents case studies to implement into environmental policies; the environmental and social aspects; pose questions to a panel
    - for projects like ours they can supply set of policies to analyze the environmental and social risk; promote the environmental and social sustainability
    - IDB is trying to implement a general regulation/advice/guidelines; trying to see if each country is trying to fulfill international standards
    - Will not sponsor a project that is a risk to society, they first analyze the social and environmental issues to prevent causing social disorder
- Relationship between government and indigenous people
    - A representative of the government brings a consultation panel to the people; indigenous communities have to be more prepared for the consultation process and educate them on the process
- Suggestions for our projects
    - Stay politically neutral
    - Keep in mind that indigenous groups vary in how they'd like to be involved in environmental cleanup
        - Each has own organizational structure
        - Very cultural and ancestral – complex and local

APPENDIX K: CABRERA REPORT APPENDIX A

APPENDIX A

SUMMARY OF THE FINDINGS RESULTING FROM THE PHYSICO-CHEMICAL CHARACTERIZATION OF THE AREA UNDER STUDY

By: Engineer. Richard Cabrera's Technical Support Team
As part of the
EXPERT REPORT

Year - 2008

I. BACKGROUND

This study is carried out to comply with item c) whereby the Judge orders the Expert:

"To verify the current existence of substances which shall affect the environment and shall or may constitute a danger for living beings and a threat for their life and way of living."

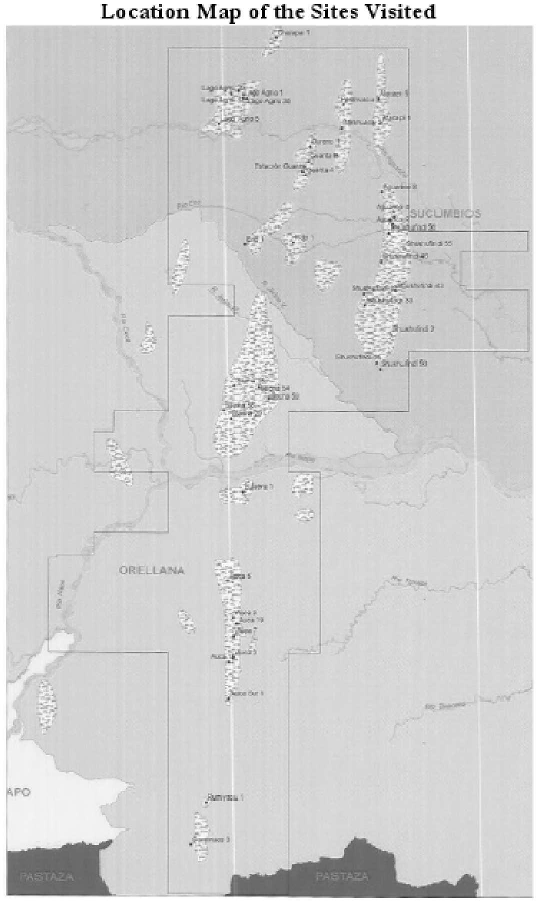
49 sites were visited and data was obtained from 48 sites.

FIELD	SITE
Aguarico	Aguarico -04, Aguarico -05, Aguarico -08, Aguarico -09, Aguarico -10,
Atacapi	Atacapi-01, Atacapi-05
Auca	Auca- 03, Auca- 04, Auca- 05, Auca- 07, Auca- 015, Auca- 19
Auca Sur	Auca Sur -01
Charapa	Charapa-01
Cononaco	Cononaco-03
Dureno	Dureno-01
Eno	Eno-01 (the owner did not allow the visit)
Guanta	Guanta Station, Guanta-04, Guanta-08

PHYSICO-CHEMICAL CHARACTERIZATION OF THE AREA UNDER STUDY

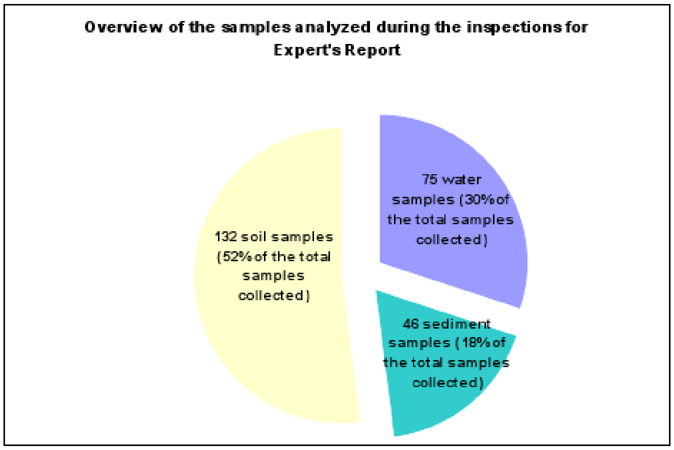
Lago Agrio	Lago Agrio-01, Lago Agrio-05, Lago Agrio-12, Lago Agrio-16, Lago Agrio-20, Lago Agrio-35
Parahuaco	Parahuaco-02, Parahuaco-03
Ron	Ron-01
Rumiyacu	Rumiyacu-01
Sacha	Sacha-18, Sacha-29, Sacha-54, Sacha-56, Sacha-60
Shushufindi	Shushufindi-02, Shushufindi-32, Shushufindi-33, Shushufindi-35, Shushufindi-43, Shushufindi-50, Shushufindi-55, Shushufindi-56, Shushufindi-61

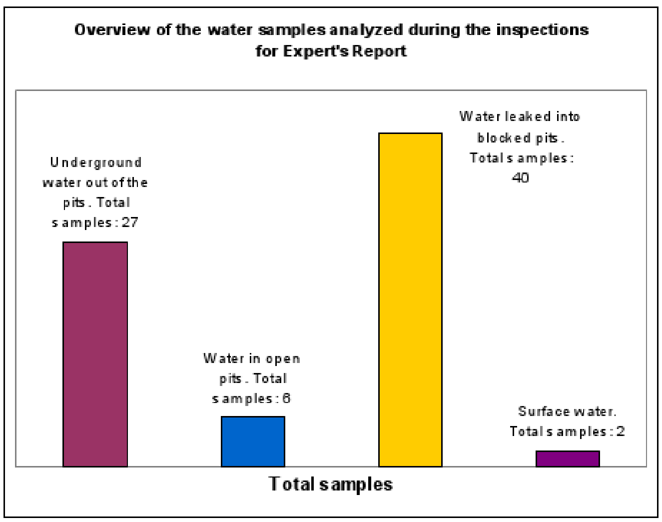
Figure 1
Location Map of the Sites Visited



2. NUMBER OF SAMPLES COLLECTED

259 samples[1] were collected, distributed as indicated in the following chart.





[1] *This Appendix and the amount of samples collected do not include the samples collected by the team of Dr. Gomez (See Appendix A) including 44 samples of water, and 79 samples of soil. The total amount of collected samples was: 211 samples of soil, 119 of water and 46 of sediments.*

3. ENVIRONMENTAL REGULATIONS APPLIED AND PARAMETERS MEASURED.

The regulations taken as reference were the following:

- Environmental Regulations for Hydrocarbon Operations in Ecuador (RAOHE) by executive decree 1215 published in the Official Record number 265 on February 13, 2001.

- Unified Text of Secondary Environment Legislation by the Ministry of Environment (TULAs) by Executive Decree number 2824 published in the Official Record number 623 on July 22, 2002.

The following parameters were analyzed and the values used for comparison are herein referred.

PAHs	Heavy Metals	Hydrocarbons
acenaphthene	Barium	TPH
Acenaphthylene[	Chromium	fingerprint
Anthracene	Nickel	
Benz-a-anthracene	Lead	
Benzo[b]fluoranthene	Vanadium	
Benzo- ghi-perylene	Chromium VI	
Benzo[k]fluoranthene		
Crysene		
dibenz(ah)anthracene		
Phenanthrene		
Fluoranthene		
Fluorene		
Indeno[1,2,3-cd]pyrene		
Naphthalene		
Pyrene		

3.1 LIMITS ESTABLISHED FOR SOIL AND SEDIMENT

The THP concentration is compared against the limits for agricultural standards and fragile ecosystems established in Table 6, Appendix 2 of the Environmental Regulations for Hydrocarbon Operations in Ecuador.

The limit established for each type of PAH was determined taking into account the values for agricultural use listed in Table 3, Appendix 2 of the Unified Text of Secondary Environmental Legislation by the Ministry of Environment, supplemented by the approximate base values and analytical detection limits for a contaminant in soil, established in Table 2, pursuant to item 4.1.3.3 of the Environmental regulations herein referred, which reads:

> 4.1.3.3 *Upon inapplicability for the specific case of any parameter set forth in this regulation, or upon absence in the regulation of a relevant parameter for the soil being studied, the Environmental Control Entity shall adopt the following assessment criteria: The entity being regulated shall determine the base or referential value for the parameter present in soil. Thus, the results obtained from the concentration present in soil are then compared against the base values. In general terms, it shall be considered that an existing*

concentration three times greater than the base value shows a level of contamination that must be immediately treated by the Environmental Control Entity (see Table 1). The procedure described shall be coordinated and supervised by the environmental control entity.

In cases where the existing concentration is three times greater than the base value, the Environmental Control Entity shall consider this situation immediately, and shall force the entity being regulated to provide soil remediation until the existing concentration becomes lower than or equal to 1.5 in comparison with the base value.

PAHs Type	Unit	TULAs Limit		Limits for each type of PAH
		Table 3 Agricultural Use	Table 2 Base value	
Naphthalene	Mg/Kg	0.1	0.1	0.1
Acenaphthylene[	Mg/Kg		0.1	0.1
Acenaphthene	Mg/Kg		0.1	0.1
Fluorene	Mg/Kg		0.1	0.1
Phenanthrene	Mg/Kg		0.1	0.1
Anthracene	Mg/Kg		0.1	0.1
Fluoranthene	Mg/Kg		0.1	0.1
Pyrene	Mg/Kg	0.1	0.1	0.1
Benzo[a]anthracene	Mg/Kg	0.1	0.1	0.1
Crysene	Mg/Kg		0.1	0.1
Benzo[b]fluoranthene	Mg/Kg		0.1	0.1
Benzo[k]fluoranthene	Mg/Kg		0.1	0.1
Benzo- a- pyrene	Mg/Kg	0.1	0.1	0.1
Indeno[1,2,3-cd]pyrene	Mg/Kg		0.1	0.1
dibenz(ah)anthracene	Mg/Kg		0.1	0.1
Benzo- ghi-perylene	Mg/Kg		0.1	0.1

The results of heavy metal concentrations are compared against the limits established in Table 2 and 3 of Appendix 2, Book VI of the Unified Text of Secondary Environmental Legislation.

3.2 LIMITS ESTABLISHED FOR WATER

The concentration of TPHs, PAHs and metals is compared with the allowable limits established in a CONDENSED TABLE developed from Tables 1,2,3, 4 and 6 of Appendix 1, Book VI of the Unified Text of Secondary Environmental Legislation pursuant to item 4.1 of Chapter 4 for the use of water for different purposes, which reads:

4.1 General Regulations of Quality Criteria for the use of surface, ground, sea and estuary waters

The regulation shall consider the following uses of water:

a) Human consumption and domestic use.
b) Plant and Animal Preservation
c) Agricultural
d) Livestock
e) Recreational
f) Industrial
g) Transportation
h) Esthetic

In case rights for the use of waters are granted for multiple purposes, the quality criteria for the use of waters shall correspond to the most restrictive values for each reference.

CONDENSED TABLE for MAXIMUN ALLOWABLE QUANTITIES of water.

PARAMETER	UNIT	PARAMETERS ESTABLISHED IN THE TULAs					CONDENSED TABLE
		TABLE 1	TABLE 2	TABLE 3 Fresh Quality	TABLE 4	TABLE 6	
TPH	Mg/L			0.50			0.50
PAHs	Mg/L			0.0003			0.0003
Naphthalene	Mg/L				0.006		0.006
Acenaphthylene	Mg/L				0.002		0.002
Acenaphthene	Mg/L						-
Fluorene	Mg/L						-
Phenanthrene	Mg/L						-
Anthracene	Mg/L						-
Fluoranthene	Mg/L						-
Pyrene	Mg/L						-
Benzo[a]anthracene	Mg/L	0.00001	0.00001				-
Crysene	Mg/L						-
Benzo[b]fluoranthene	Mg/L						-
Benzo[k]fluoranthene	Mg/L						-
Benzo- a- pyrene	Mg/L						0.0001
Indeno[1,2,3-cd]pyrene	Mg/L						
dibenz(ah)anthracene	Mg/L						
Benzo- ghi-perylene	Mg/L						-

Cr+6	Mg/L	0.05	0.05			0.10	0.05
Ba	Mg/L	1.00	1.00	1.00		1.00	1.00
Ni	Mg/L		0.025	0.025		0.20	0.025
V	Mg/L		0.10		0.10	0.10	0.10
Total Cr	Mg/L			0.05			0.05
Pb	Mg/L	0.05	0.05			0.05	0.05
Human and Agricultural use: TABLES 1,2,3,4,6							
TABLE 1: maximum allowable limits in water for human consumption and domestic use, only requiring conventional treatment.							
TABLE 2: maximum allowable limits in water for human consumption and domestic use, only requiring disinfection							
TABLE 3: Admissible quality criteria for animal and plant preservation in cold, warm and fresh water, and in sea and estuary waters.							
TABLE 4: additional maximum allowable limits for the interpretation of water quality.							
TABLE 6: Admissible quality criteria in waters for agricultural use.							

4. LABORATORIES INVOLVED AND QUALIFICATIONS

In order to assure the validity of results, additional certified laboratories, authorized by the OAE (Ecuadorian Accreditation Body) were required. The following laboratories were involved and the analyzed parameters are detailed below:

LABORATORY	MATRIX	PARAMETER	ACCREDITATIONS AND QUALIFICATIONS
Gruentec	- Drinking, natural, residual and sea waters. - Soils and sediments	Chromium, Barium, Nickel, Lead, cadmium, PAHs, Nickel, Chromium, Lead, Barium, PAHs	Qualified by Environmental Protection Undersecretary and the Canadian Association for Environmental Analytical Laboratories Inc.
LabSu	- Natural, residual and treated waters. - Soils and sediments	Barium, Chromium, Lead, Vanadium, TPH. TPH	Ecuadorian Accreditation Body (OAE)
Umwelt	- Soils and Sediments	Barium, Nickel, and Vanadium. Fingerprinting	Ecuadorian Accreditation Body (OAE)

In the corresponding appendices, the necessary information for each laboratory can be found.

5. QUALITY CONTROL

All soil, sediment and water samples were collected pursuant to the methodology already established appearing in Appendix PO. Operating Procedure.
The labeling, conservation and transportation regulations for samples set forth in this appendix are complemented with photographs of the sampling, labeling and conservation.

The quality control process and sample transportation sheets are contained in Appendix CC of this report.

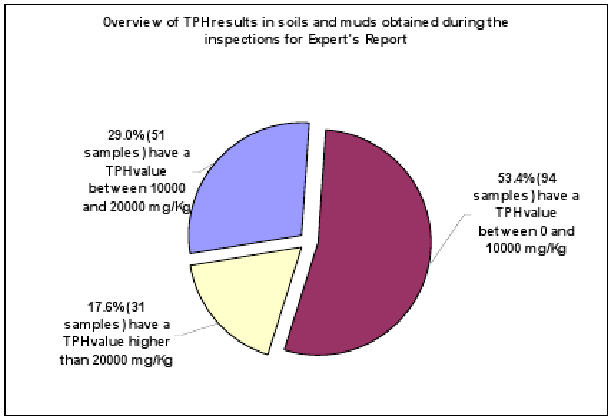
All analytical results are supported by the standard used for sample analysis; these results are contained in Appendix RC. Laboratory Results and Analysis Quality Control.

6. RESULTS.

6.1 SOIL AND SEDIMENT SAMPLES

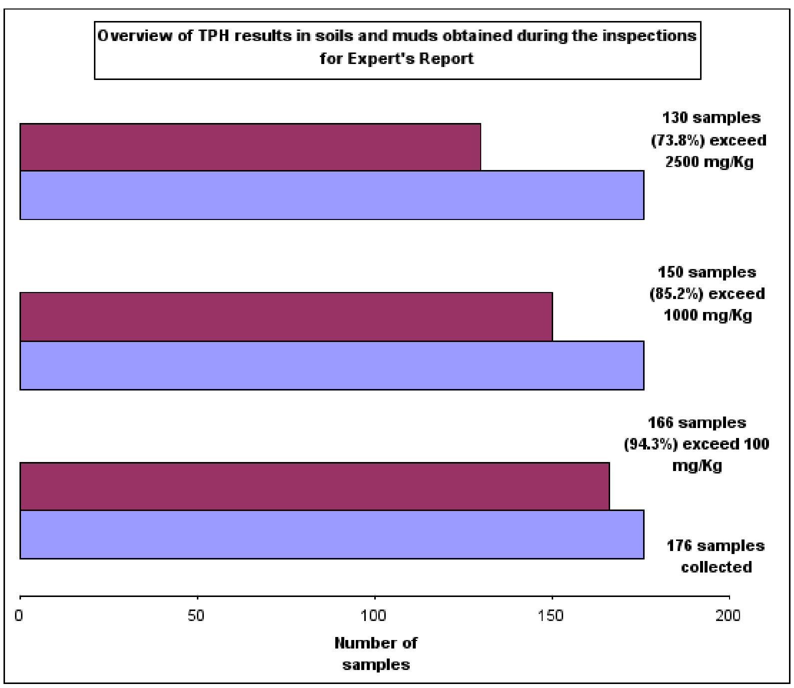
6.1.1 TPH Concentration

TPHs were analyzed in 176 samples, of which 130 were soil and 46 were sediment. Three ranges of comparison were established with the results obtained and it was concluded that:



It was also proved that the laboratory results show values which exceed the limits established in the environmental regulations, thus:

- 130 samples show values greater than 2,500 mg/Kg of TPH established for agricultural use in the RAOHE which corresponds to 73.86 % of the total value.
- 154 samples have values greater than 1.000 mg/kg of THP determined for fragile ecosystems in the RAOHE which correspond to 87.50% of the total value.



6.1.2 PAH Concentration

In 177 collected samples, 16 types of PAHs were analyzed in the laboratory and it was found that:

- 86 samples show values of some type of PAH at the detection limit of the method used for the analysis which is <0.50 mg/Kg. In 91 samples, the compliance or non-compliance with the limit established of <0.1 mg/Kg, which is lower than the detection limit of the laboratory, cannot be determined

- Two ranges for the concentration of existing PAHs, pursuant to the limits established, were determined out of 86 samples; the table below shows the type of PAH, the number of samples in which it is present, and the percentage in which it is present in each of the ranges established.

PAHs Analyzed	TOTAL SAMPLES	PAHS ≥1.0		0.5≤PAHs<1.0	
		Number of Samples	Percentage	No of samples	Percentage
Naphthalene	44	37	84.09%	7	15.91%
Acenaphthylene	3	2	66.67%	1	33.33%
Acenaphthene	9	5	55.56%	4	44.44%
Fluorene	18	12	66.67%	6	33.33%
Phenanthrene	67	43	64.18%	24	35.82%
Anthracene	3			3	100.00%
Fluoranthene	1			1	100.00%
Pyrene	9	2	22.22%	7	77.78%
Benzo[a]anthracene	26	11	42.31%	15	57.69%
Crysene	8	3	37.50%	5	62.50%
Benzo[b]fluoranthene	1			1	100.00%
Benzo (a) Pyrene	8	5	62.50%	3	37.50%
Benzo- ghi-perylene	2	1	50.00%	1	50.00%

- In addition, the existence of Benzo (k) Fluoranthene, Indeno (1, 2, 3- cd) pyrene and Dibenzo (ah) anthracene cannot be determined since the detection limit of the method used for the analysis is greater than the limit established.

6.1.3 Concentration of Metals.

BARIUM, NICKEL and **VANADIUM** were analyzed in the laboratory in 12 samples taken from the field. Three ranges were established for each of the metals, taking as a basis the limit established for agricultural use, and the base value established by Ecuadorian Regulations.

- To analyze **BARIUM**, eight samples were taken, and the following was determined:

- o 5 samples have concentrations lower than 200 mg/Kg which corresponds to 62.50% of the total value.
- o 2 samples show values between 200 and 750 mg/Kg which corresponds to 25% of the total value.

- 1 sample has a value greater than 750 mg/Kg which corresponds to 12.50% of the total value.
- 3 samples show concentrations greater than 200 mg/kg which corresponds to 37.50 % of the total value.

- To analyze **NICKEL** , eight samples were taken, and the following was determined:

    - 4 samples show values lower than 20 mg/Kg which corresponds to 80% of the total value.
    - 1 sample has a concentration between 20 and 50 mg/Kg which corresponds to 20% of the total value.

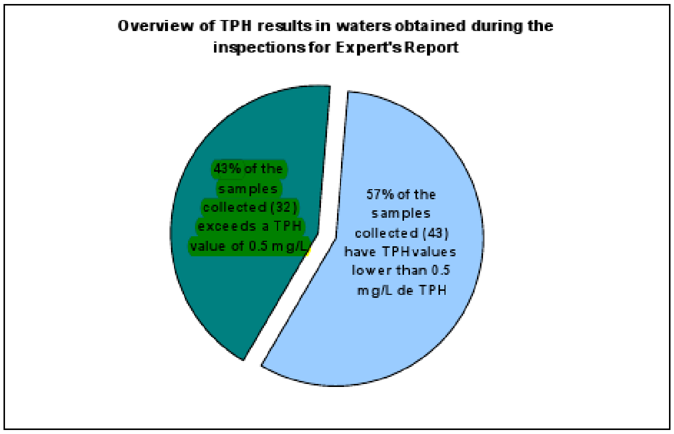
- To analyze **VANADIUM**, five samples were taken, and it was found out that they have values between 25 and 130 mg/kg, establishing, that they do not comply with the base value set forth in the regulations.

6.2 WATER SAMPLES

6.2.1 TPH Concentrations.

TPH was analyzed in 73 samples: 27 samples of groundwater outside the pits, five samples of water contained in open pits, 39 samples of the water column contained in the soil of covered pits and two samples of surface water. Three ranges of comparison with the results obtained were established, and the following was determined:

- 43 samples show values lower than 0.5 mg/L of TPH which corresponds to 57.33 % of the samples.
- 7 samples have concentrations between 0.5 and 1.0 mg/L of TPH which corresponds to 9.33 % of the samples.
- 25 samples show concentrations greater than 1.0mg/L of TPH which corresponds to 33.33% of the samples.
- 32 have values greater than 0.5 mg/L of TPH which corresponds to 42.67 % of the samples.



6.2.2 PAHs Concentration

16 different types of PAHs were analyzed in the laboratory in 46 samples collected, and it was found that:

- 8 samples show concentrations of some type of PAH above the detection limit of the method used for the analysis which is <0.0002 mg/L; where in 38 samples the presence of these contaminants could not be determined because the values were below the detection limit.

- The following PAHs were detected in the 8 samples: Naphthalene, Phenanthrene, Anthracene, and Benzo (a) anthracene.

    - Anthracene was present in 5 samples, where 1 sample showed a concentration greater than the established limit of 0.0006 mg/L.
    - Phenanthrene was present in 5 samples; 2 samples showed traces of Anthracene and 3 samples showed traces of Benzo (a) anthracene.

- The existence of Benzo (a) pyrene cannot be determined in the 46 samples collected since the detection limit is greater than the established limit of 0.00001 mg/kg; notably, this element is considered to be a carcinogen element, and the most representative PAHs pursuant to the EPA.

6.2.3 Concentration of Metals.

58 Samples of **BARIUM, HEXAVALENT CHROMIUM, TOTAL CHROMIUM, NICKEL, VANADIUM AND LEAD** collected from the field were analyzed in the laboratory. The results for each of the metals were compared with the limit established in the Condensed Table contained in the Environmental Regulation.

PHYSICO-CHEMICAL CHARACTERIZATION OF THE AREA UNDER STUDY

- In order to analyze **BARIUM**, 58 samples were taken and it was determined that only 2 samples show values greater than the detection limit of the method used; only one of these samples does not comply with the established value.

- In order to analyze **HEXAVALENT CHROMIUM, NICKEL AND LEAD**, 30, 8 and 8 samples were collected respectively. The results obtained do not allow for determination of the existence of metals due to the fact that the values reported by the laboratory correspond to the detection limit of the method used.

- In order to analyze **TOTAL CHROMIUM AND VANADIUM,** 40 and 22 samples were collected respectively. The results obtained do not allow for determination of the existence of metals due to the fact that the values reported by the laboratory correspond to the detection limit of the method used.

Metal analyzed	Number of samples collected	Number of samples higher than the laboratory detection limit	Number of samples higher than the background value	Number of samples higher than the accepted limit
Barium (Ba)	58	2	1	-
Hexavalent chromium (Cr VI)	30	-	-	-
Nickel (Ni)	8	-	-	-
Lead (Pb)	8	-	-	-
Total chromium (Cr)	40	-	-	-
Vanadium	22	-	-	-

6.3 CRUDE OIL SAMPLES.

Eight samples were also collected, and a fingerprinting was carried out to determine the structure of the existing crude oil

6.4 CONCLUSIONS

– Of the 176 samples analyzed to find TPH in soil, it was determined that 154 show values which do not comply with the values established in the RAOHE for soils.

–Of the 177 samples collected to analyze PAHs in soil, it was determined that 86 have concentrations of some type of PAH which exceeds the established limit. Moreover, it is not possible to determine the compliance of the other PAHs due to the fact that the value reported by the laboratory corresponds to the detection limit of the method used.

–Of the 12 samples in which metals in soil were analyzed:

- 3 samples show concentrations of Barium greater than the two limits established.
- 1 sample has nickel values greater than the limits established.
- 5 samples show Vanadium values greater than the limits established.

–Of the 75 samples analyzed for THP in water, it was determined that 32 samples have concentrations exceeding the established limit.

–Of the 46 samples collected for analyzing and determining the existence of PAHs in water, it was determined that 8 samples contain values of the same type of PAHs which exceeds the limit established for each one. Moreover, it is not possible to determine the compliance of the values of the other PAHs, since the concentrations reported by the laboratory correspond to the detection limit of the method used.

–2 out of 58 samples analyzed to determine the existence of metals in water show that the concentration of Barium is greater than the limit established. In the case of **Total Chromium** and **Vanadium**, compliance with the limits established cannot be determined since the concentrations reported by the laboratory correspond to the limit of detection of the method used.

7. SUMMARY OF THE RESULTS OF THE INSPECTIONS CARRIED OUT

From July 4th to September 28th, 2007, 48 sites (collecting samples only in 44 wells) and one production station were inspected to determine the current conditions; the contamination levels in water, soil and sediment were established. Afterwards, from October 15th to November 3rd, the data set was complete with the collection of water samples in 33 of the sites inspected.

For each location data was collected and organized into seven categories, and it is contained in Appendix RSS (U4): Results site by site:

Geographical Information: describes political and access information for the inspection sites which is complemented by a location map of the site area.

Observation on aerial photographs taken by IGM: analyzes shapes found in aerial photographs taken by the Military Geographic Institute (IGM) prior to 1990 and attributed to pits and/or spills. This information was verified against the findings obtained in the field during the inspections, and against the information given by the people living in the area.

PHYSICO-CHEMICAL CHARACTERIZATION OF THE AREA UNDER STUDY

Current use of soil: describes on a map, vegetation distribution and soil use in the areas near the inspected sites.

Sampling general observations: summarizes the number of pits, water formations and additional information found out during the inspections.

Location of the area inspected and samples collected indicates the codes of the samples collected and their location in coordinates UTM WGS-84, and is supplemented with an approximate sketch of the area inspected and the samples collected. In Appendix A: Lithology, the drilling and material found are described.

Laboratory results: compares tables and graphics of the values obtained with the limits established in the regulations. This information is supplemented by Appendix A. Laboratory results, Quality Control of the Analysis; Accreditation Certificates for Laboratories, Custody Chain and Transportation Sheets of Samples.

A. CHARAPA 01.

The area consists of three open pits with crude oil and a swamp area to the west of pit 2. 12 samples were collected in the pits: three soil, one water, and one crude oil sample were collected from pit 1. One soil sample and one water sample, apart from the sample CHA1-PIT2-SD1-AC which was not analyzed because it was contaminated with crude oil, were collected from pit 2. In pit 3, three soil samples, one sediment sample and one water sample were collected. A water sample was also taken in the swamp area to the West of pit 2. TPH and PAHs were analyzed in all the soil, sediment and water samples, and the existence of Chromium VI, Barium, Nickel and lead in waters was also analyzed. In the crude oil sample, a fingerprinting was carried out to determine its composition. From the results obtained, it was determined that TPH and PAH concentrations in the soil, sediment and water of the pits show values which exceed the allowable limits set forth in Ecuadorian Environmental Rules.

B. LAGO AGRIO 1.

Two pits were found, one was a covered pit in the area of the burner. The other was a pit of water located to the northeast of the wellhead. A total of five samples were collected in the pits: three soil samples, one sediment sample, and one water sample. A sample of sediment and a sample of water were also taken in the external area of pit 1. In the soil, sediment and water samples, TPH and PAHs were analyzed. Additionally, Barium was analyzed in sample LAG01 -PIT1-SD2-SU2-R(240-280)cm, and Hexavalent Chromium, Barium, Nickel, and Lead were analyzed in sample LAG01-A 1 -S DI-AF 1-NF(10). From the results obtained, it was determined that the soil and sediment samples of the pits show TPH and PAH values which exceed the limits established by the regulations. It was also determined that the Barium concentration in pit 1 has values which do not comply with the base limit established. Sediment and water samples collected from the external area of pit 1 show TPH values which do not comply with the limits established.

PHYSICO-CHEMICAL CHARACTERIZATION OF THE AREA UNDER STUDY

C. LAGO AGRIO 35.

A pit and a swamp area were found to the West of the platform. In the pit, three soil samples and one water sample were taken. Two sediment samples and one water sample were also taken in the western and northern soil of the pit. TPH and PAHs were analyzed in all soil, sediment and water samples, and barium and lead were analyzed in water samples. From the results obtained, it was determined that the TPH concentration in the soil, sediment and water samples show values which exceeded the allowable limits set forth in the Ecuadorian Environmental Regulations. It was also proven that the PAH values exceed the limits specified for PAH in the soil of the pits.

D. LAGO AGRIO 12

A pit was found to the west of the platform. A total of five samples were collected: two soil samples and two water samples were taken in the pit, and one water sample was taken northwest of the pit. TPH and PAHs were analyzed in all the samples, except in sample LAG12-PIT1-SD2-AF-NF (110) cm where only TPH was analyzed. Additionally, Hexavalent Chromium, Barium, Nickel and Lead were analyzed in sample LAG12-PIT1-SD1-AF1-NF (100). Soil samples show values which exceeded the limits established for TPH and PAHs. Water samples indicate that, within the pit and the external area, the values are greater than the limit established.

E. LAGO AGRIO 16B.

Three pits were identified. A total of 10 samples were collected: three soil samples and two water samples were taken in pit 1. Two soil samples were taken in pit 2; and two water samples were taken in the gooseneck exit, and one to the northwest of the pit. Moreover, one sediment sample was taken to the north. TPH and PAHs were analyzed in all the samples. Additionally, barium was analyzed in the soil sample LAG16-PIT1-SD3-SU1-R (180-200) cm, and the existence of Hexavalent Chromium, Barium, Nickel and Lead was analyzed in the water samples LAG16-PIT1-SD1-AF1-NF (250) and LAG16-PIT1-SD2-AF1-NF (140).

Soil samples in the pits and in the external area of pit 1 show TPH and PAH values which EXCEED the limits established for analysis. It was also determined that the area of pit 1 shows a concentration of Barium that does not comply with the limits established. From the results of water samples, it was determined that there are hydrocarbons in pit 1 and in the gooseneck exit.

PHYSICO-CHEMICAL CHARACTERIZATION OF THE AREA UNDER STUDY

F. LAGO AGRIO 20.

Lago Argio has at least four pits. A total of nine samples were collected: two soil and one water sample were taken north of pit 1, one soil sample and one water sample were taken southwest of pit 4, one sediment sample, one water sample and one crude oil sample were taken from pit 3. TPH was analyzed in all samples, and PAHs were analyzed in soil and sediment samples; and LAG20-AI-SD -AF1-NF (5) and LAG20-PIT3-SD1-AF1-NF (30) were analyzed to find heavy metals. A fingerprinting was carried out to determine the composition of the crude oil existing in pit 3. In pits 1 and 3, there are concentrations of TPH and PAHs in soil which exceed the limits established in RAOHE, whereas the values of water samples collected in pit 3, and in the southeastern part of pit 4, show TPH concentrations greater than the limit established.

G. LAGO AGRIO 05

Two pits and a swamp area were located. A total of four samples were collected, two samples of sediment, one in each pit, and two samples of water, one in pit 2 and the other in the swamp area. TPH and PAHs were analyzed in all the samples. Additionally, in the water sample LAGO5-PIT2-SD1-AF1-NF (200), Hexavalent Chromium, Barium, Nickel and Lead were analyzed. Soil samples show THP and PAH concentrations which exceed the limits established in the RAOHE; whereas the water sample collected from pit 2 indicates the existence of TPH in percolating water.

H. PARAHUACU 02.

Three pits were located. A total of four soil samples were collected: two samples in pit 1, and two samples in pit 2. TPH and PAHs were analyzed in the samples. The results obtained established that there are concentrations which DO NOT COMPLY with the limits established.

I. PARAHUACU 03.

Two pits were found. Contamination was found in pit 1. Three soil samples were taken in pit 1, and TPH and PAHs were analyzed. From the results obtained, it was concluded that there are TPH and PAH concentrations which exceed the limits established.

J. ATACAPI 01 WELL

There are at least two covered pits. Five samples were taken in all: four soil samples, three in pit 1, and one in pit 2, and one water sample was taken in the floodable area under the gooseneck of pit 2. TPH and PAHs were analyzed in all soil samples, and TPH, Barium and Total Chromium were only analyzed in the water samples. The results show that the concentrations exceeded the limits established in the RAOHE. The existence of TPH was also identified in the floodable area under the gooseneck.

PHYSICO-CHEMICAL CHARACTERIZATION OF THE AREA UNDER STUDY

K. ATACAPI 05 WELL

There are at least two covered pits, and a swamp area was found to the south of pit 2. Eight samples were taken in all: 2 samples in pit 1, and one sample in pit 2. Two sediment samples and one water sample were also collected to the north of pit 1; and 2 water samples and 1 sediment sample were collected from the swamp area to the south of pit 2. TPH and PAHs were analyzed in soil samples, and TPH and Total Chromium were analyzed in water samples. Additionally, in sample ATA05-A2- SD-1-AF1-NF (5) tests for determining the existence of PAHs, Chromium VI, Barium and Vanadium were carried out. Soil samples in pit 1, and to its the northern area, show TPH concentrations greater than the limits established in the RAOHE, where sediment in the swamp area has values that exceed the limit for Fragile Ecosystems set forth in RAOHE. The water sample taken to the north of pit 1 indicates the existence of TPH in water.

L. GUANTA 04 WELL

One pit was found. Four samples were collected in all: two soil samples and one water sample were collected in the pit. In the external area of the pit to the east, one water sample was collected. TPH and PAHs were analyzed in soil samples. TPH and Barium were analyzed in water samples, and in GTA04-PIT1-SD1-AF1-NF (50), tests for determining the existence of Total Chromium were also carried out. The TPH concentration in soil shows values greater than the limits established in RAOHE.

M. GUANTA 08 WELL

The existence of a pit and an area of interest were verified. Five samples were collected: two soil samples and two water samples were collected from the pit, and one water sample was collected from the contaminated area. TPH and PAHs were analyzed in all samples. The existence of Chromium VI, Barium, Nickel and Total Chromium was investigated. In the pit, it was determined that the TPH concentrations in soil and water show values which do not comply with the limits established for comparison. PAHs concentration in soil exceeds the limit established.

N. DURENO 01 WELL.

The existence of one pit to the southeast of the platform was confirmed. Four samples were taken, and TPH and PAHs were analyzed. From the results obtained, it was determined that TPH and PAH concentrations show values greater than those established for analysis.

O. AGUARICO 04 WELL

AGUARICO 04 has three pits where sediment samples were taken. Two sediment samples were taken to the north west of the pit. TPH and PAHs were analyzed in the samples collected and it was found that their concentrations exceeded the limits established in pits 1 and 3, and in the area to the northeast of the pit. The value found in pit 2 is greater than the limit established for fragile ecosystems.

P. AGUARICO 05 WELL

AGUARICO 05 has three pits. Three soil and one crude oil sample were collected in pit 1. In each of pits 2 and 3, one soil sample and one water sample were collected. TPH and PAHs were analyzed in all the samples. Additionally, Nickel and Vanadium were analyzed in AGU5-PIT1 -SD1 –SU1-R (60-140) cm; Chromium VI, Barium, and Total Chromium were analyzed in the water samples. TPH concentrations in soil and water samples show values greater than the limits established. In addition, pits have PAH values which do not comply with the provisions set forth in the Ecuadorian Environmental Regulation.

Q. AGUARICO 08 WELL

Two pit and two swamp areas were located to the north and south of the platform. Nine samples were taken: three soil and one water sample were taken in pit 2, one soil and one sediment were taken respectively from pits 1 and 3, and two water samples and one sediment sample were collected from the swamp area to the south. TPH and PAHs were analyzed in all samples. Additionally, Barium and Total Chromium were analyzed in the following water samples: AGU08-PIT1 –DS1-AF 1 -NF (10) and AGU08-A1-SD 1-AF1 -NF (0). TPH and PAH concentrations in soil and sediment in pit 2, and in the swamp area to the south, respectively show values which do not comply with the values established in RAOHE. On the other hand, the results of the samples collected in these sites indicate the existence of hydrocarbons.

R. AGUARICO 09.

The existence of at least four pits was determined. Eight samples were collected in all: four water samples in pit 2, one water sample in pit 4, and one water sample and two sediment samples in pit 1. TPH was analyzed in soil and water samples. PAHs were analyzed in all soil samples and in sample AGU9-PIT1- AS. Additionally, Vanadium and Nickel were analyzed in AGU9-PIT2-SD2-SU2-R (230-250) cm. Also, Barium and Total Chromium were analyzed in samples AGU09-PIT1-SD1-AFI-NF (200). TPH soil concentration in pits show values which exceed the limits established in the RAOHE. PAH values in pit 2 show values which exceed the limit established. In addition, the metal concentration in pit 2 indicates that there is Nickel and that the Vanadium value exceeds the base values set forth in the TULAs. The results show the existence of TPH in the water of pit 1.

S. AGUARICO 10

The existence of three pits and one swamp area was determined. Eleven samples were taken in all: one sample of crude oil in the platform; three soil samples and two water samples were taken in pit 1, two soil samples and a water sample were taken in pit 2, one soil sample in pit 3. A sediment sample was collected to the southeast of pit 3. TPH and PAHs were analyzed in soil.

Barium was analyzed in sample AGU10-PIT1 -SD2-SU1-R (60-l0) cm. TPH, Barium and Total Chromium were analyzed in water. A fingerprinting was carried out in the sample of crude oil to determine its composition. The resulting value of TPH in the soil in pit 1 and 3 and in the southeastern area show values which exceed the limits established in RAOHE. In pit 2, the concentrations do not comply with the limit set forth for fragile ecosystems in the above mentioned regulations. The PAH values were also determined in those pits exceeding the limit established for analysis. In pit 1, there is Barium. It was determined that in water samples, TPH concentrations in percolating water in pit 1 and 2 do not comply with limit established.

T. SHUSHUFINDI 46.

Six samples were taken in two pits: two water samples and one soil from pit 1, one water and two soil from pit 2. TPH was analyzed in all samples. PAHs were also analyzed in soil samples and in SSF46-PIT1 -SD1-AF. Barium and Total Chromium were analyzed in SSF46-PIT1-SD1-AF1-NF (40) and SSF46-PIT2-SD1-AF1-NF (60). Soil results show that TPH and PAH concentrations in pit 2 have values which exceed the limits established in the RAOHE. TPH was found in the percolating water of pit 1.

U. SHUSHUFINDI 55

By means of aerial photographs and field work, a pit and a swamp area were found southeast of the platform. In these areas, nine samples were taken: five soil and one water sample from pit 1, two sediment and one water sample were collected from the swamp area. TPH was analyzed in all samples. PAHs were analyzed in soil samples and in SSF55-PIT1-SD1-AF1-R (20-500). Additionally, Barium and Total Chromium were analyzed in the two water samples. And in pit 1, Hexavalent Chromium and Vanadium were analyzed. TPH concentration in soil and percolating water in pit 1, and sediment in the swamp area, show values which exceeded the values established in the current environmental regulations. In the soil and sediment of the pit and in the swamp area, the PAH values do not comply with the limits established.

V. SHUSHUFINDI 56

An open pit of crude oil was found, and one water and two sediment samples were collected from the pit. TPH and PAHs were analyzed in all the samples. Additionally, Barium was analyzed in SSF56-PIT1-SE2, and Hexavalent Chromium, Barium, Vanadium and Total Chromium were analyzed in the water samples. The results show that the TPH concentrations of soil and sediment samples do not comply with the limits set forth in the current environmental regulations. It was also determined that the sediment has PAH values which are greater than the limit established for these contaminants. Barium concentration in soil exceeds the base values established in TULAs.

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W. RON 01.

A pit and a swamp area were located and today the well is abandoned. Five samples were collected in all: two soil samples from pit 1, and two water samples and one sediment sample from the swamp area. TPH and PAHs were analyzed in all samples. Additionally, Nickel and Vanadium were analyzed in sample RON1-PIT1-SD 1 -SU 1- R (350-380) cm. Hexavalent Chromium, Barium, Vanadium and Total Chromium were analyzed in water samples. From the results obtained, it was determined that all samples show TPH concentrations which exceed the limits established in the current regulations. In the soil of the pit, the existence of Barium was detected and the Vanadium concentration does not comply with the base value set forth in the TULAs.

X. CONONACO 03.

Three covered pits were found. A sediment sample was collected in each pit; and TPH and PAHs were analyzed in each sample. In pit 1 and 2, there are values which exceed the limit established for Fragile Ecosystems in RAOHE. In pit 3, the concentration is greater than the two limits established in the regulation mentioned herein.

Y. AUCA SUR 01.

A covered pit, an open pit with water, and an area contaminated due to a spill were found. Nine samples were collected in all: three soil samples from the covered pit were taken. One sediment sample was taken from pit 2. Two samples of percolating water outside of pit 2 and one sample outside of its gooseneck were collected. In the area of the spill, one sediment sample, one water sample, and one sample of crude oil were collected. TPH was analyzed in all samples. PAHs were analyzed in soil, sediment and water samples and in samples 4UCS01 -Al -AS1-R (20-120) and AUCS01-A2-SD2-AF1-NF (100). Additionally, Barium, Chromium VI, Vanadium and Total Chromium were analyzed in the samples collected from the area of spill. Barium, Total Chromium and Vanadium were also analyzed in the other samples. A fingerprinting was carried out in the crude oil sample to determine its composition. TPH concentrations in the sediment of pit 2 and in the spill area show values which are greater than the limits established in the RAOHE. Concentration in pit 1 exceeds the limit established for Fragile Ecosystems in the regulation herein mentioned. The results obtained for the analysis of percolating water in the area outside pit 2 and in the spill area, indicate that TPH concentrations are greater than the limit established. The existence of Naphthalene was also detected.

Y. RUMIYACU 01

Three pits were identified, two covered pits and one open pit in which the PEPDA project was performing restorations activities. Six samples were taken in all: three soil samples of from pit 1, and two soil samples from pit 2. One water sample was collected from the area outside pit 2. TPH and PAHs were analyzed in soil samples; and TPH, Barium, and Total Chromium were analyzed in water samples. TPH concentration in the soil of the pits is greater than the limits established by the RAOHE. Additionally, the TPH results in water indicate the existence of this contaminant.

AA. AUCA 15.

There is at least one pit, from which one water sample and a soil sample were taken. TPH and PAHs were analyzed in the first sample. TPH, Barium and Total Chromium were analyzed in the second sample. The results showed that in the soil of this pit there are TPH concentrations greater than the limits established in the RAOHE. It is also determined that the percolating water of this pit contains TPH.

BB. AUCA 03.

The existence of a covered pit was determined. A soil sample was collected, and TPH and PAHs were analyzed. The results show that the soil of the pit contains TPH.

CC. AUCA 07.

There are at least two covered pits and a ditch. Six samples were collected: two soil and one water from pit 1, one sediment and one water from pit 2, and one sediment sample from the ditch. TPH and PAHs were analyzed in soil and sediment samples. TPH, Barium and Total Chromium were analyzed in the water samples. Results indicate that the TPH concentration of the three sites show concentrations which are greater than the limits established in the RAOHE. It was also determined that in pit 1, the water sample has a TPH value greater than the limit established in the TULAS. In pit 2, the existence of this contaminant was also determined.

DD. AUCA 19B.

It was determined that there is at least one covered pit with evidence of contamination. Five samples of soil and two samples of percolating water were collected. TPH and PAHs were analyzed in the soil samples. TPH was also analyzed in the water sample and additionally, Barium, and Total Chromium were analyzed in AUC19-PIT1-SD1-AF1-NF (20). From the laboratory results, it was determined that in the pit there are TPH concentrations in soil and percolating water which exceed the limits established in the RAOHE and TULAs respectively. It was also found that the Barium concentration in percolating water has a value which exceeds the limit established.

EE. AUCA 05.

Two pits and an area northeast of pit 2 were found. Five samples were collected in these sites: one soil from pit 1, two water and one sediment from pit 2, and one sediment sample in the northwestern area of pit 2. THP and PAHs were analyzed in all samples. Hexavalent Chromium, Barium, Vanadium and Total Chromium were analyzed in the water samples. According to the laboratory results obtained, it was determined that the soil of pit 1, the sediments of pit 2 and the area to the northwest, show TPH concentrations greater than the limits established by the RAOHE. It was also determined that the percolating water in pit 2 shows TPH and PAH concentrations which do not comply with the limit established in TULAS. Moreover, the existence of Barium in this pit was identified.

FF. YULEBRA 01.

There is a pit composed of a covered pit called PIT2 and of another open pit containing crude oil and water. In these sites, five samples were collected: two soil samples in the area of pit 2 which is covered and one water (contained in the pit), one sediment, and one sample of crude oil from the open pit. TPH and PAHs were analyzed in the soil, sediment and water samples. Additionally, Hexavalent Chromium, Barium, and Vanadium were analyzed in water samples. A fingerprinting was also carried out in the samples of crude oil to determine their composition. Sediment in open pit 1 of crude oil shows a TPH concentration which is greater than the limits established in the RAOHE. The water results indicate the existence of contaminant in water.

GG. YUCA 09.

Yuca 09 has two pits. Seven samples were taken: two sediment and one water from pit 1, two crude oil and one water and one sediment from pit 2. TPH and PAHs were analyzed in all samples. Additionally, Barium was analyzed in YUC09-PIT1-SE; and Barium, Nickel and Vanadium were analyzed in YUC09-PIT1-SE2. Hexavalent Chromium, Barium and Vanadium were analyzed in the two water samples. A fingerprinting was carried out in the crude oil sample in order to determine its composition. The results obtained from the TPH in sediments and water contained in the pits show values which exceed the limit established in the RAOHE and TULAs respectively. It was also determined that sediment in pit 2 exceeds the limit established, and that the water sample of pit 1 indicates the existence of naphthalene. Results of sediment samples in pit 1 indicate the existence of Barium and Nickel in the site; moreover, the Vanadium concentration does not comply with the TULAs.

HH. SACHA 54

Based on aerial photographs and field work, the existence of a covered pit was determined. Two soil samples were taken. TPH and PAHs were analyzed in SAC54 – PIT1-SD1-SU1-R (40-130) cm, and Barium was analyzed in SAC54 – PIT1-SD1-SU2-R (130-140) cm. Results indicate the existence of TPH and Barium in the soil of this pit.

II. SACHA 29.

There are three pits. Eight samples were taken: three percolating water and three soil from pit 1, one soil from each of pits 2 and 3. TPH and PAHs were analyzed in all samples. Additionally, Chromium VI, Barium, Vanadium and Total Chromium were analyzed in water samples. Only the SAC-29-PIT1-SD2-AF sample was sent to CORPLAB to be analyzed. TPH and PAH results established that in the area of pit 1 and 2, where there are concentrations that do not comply with the limits established by the TULAs and RAOHE respectively. It was also established that the soil of pit 3 has a value exceeding the limit established for Fragile Ecosystems in RAOHE. Percolating water in pit 1 has a greater TPH concentration than the limit established by TULAs.

JJ. SACHA 56.

Two pits and two areas were located to the north of the platform and to the west of pit 1. In the influence area of the platform a total of 12 samples were taken: four samples of soil and two of percolating water from pit 1, two soil samples and one sample of crude oil from pit 2. In the northern area of the platform, one sediment sample, and in the western area of pit 1, one sediment sample and one water sample were taken. In the water and soil samples of pits TPH and PAHs were analyzed, and in water samples Hexavalent Chromium, Barium, Nickel and Total Chromium were analyzed. In the samples taken in the investigated areas TPH and PAHs were analyzed. In the sediment and water samples only TPH and Barium were analyzed. In the sample of crude oil, a fingerprinting was carried out to determine its composition. Based on the results, it was determined that in the soil of the pits and the sediment of the areas there were TPH concentrations greater than the limits established by RAOHE. In the soil of pit 1, Naphthalene concentrations that do not comply with the limit established by TULAs were also found. The percolating water in pit 1 has TPH values that exceed the limit set forth in the standard and in the west area of this pit this contaminant appeared in the water.

KK. SACHA 18.

Based on aerial photographs and field work, the presence of two pits with evidence of contamination was observed. Seven samples were taken in these pits: one soil from pit 1, and percolating water from outside area of the pit, and three soil samples and two of percolating water from pit 2. TPH and PAHs were analyzed in all samples. Additionally, Chromium VI, Barium, Vanadium and Total Chromium were analyzed in waters.

It was established from the laboratory results that TPH concentrations in soil and water samples have values that exceed the limits established by RAOHE and TULAs; it was also established that soil and water samples outside pit 1 have concentrations of PAHs that do not comply with the limits set by TULAS.

LL. SACHA 59.

Evidence of contamination in five pits and in an area to the northeast of pit 1 was observed. Eight samples were taken at these sites: two soil from pit 1, one soil from pit 2, two soil from pit 3, one soil from pit 4, one sediment from pit 6, and one sediment sample from the northeastern area of pit 1. TPH and PAHs were analyzed in all samples.

From the results of laboratory tests it is stated that the TPH concentration of all the inspected sites, except for pit 2, have values that do not comply with the limits established by RAOHE. It was also found that PAH concentrations in pit 1, 3 and 6 have values which exceed the limit established by TULAS.

MM. SHUSHUFINDI 50.

A pit identified as PIT3, was located where one sediment and one percolating water sample was taken; in both samples TPH and PAHs were analyzed. In addition, Chromium VI, Barium, Vanadium and Total Chromium were analyzed in the water samples. The results indicate that the TPH concentration in sediment and water samples have greater values than the limits set by RAOHE and TULAs. It was also found that PAH concentrations in the sediment have values which do not comply with the provisions of the TULAs.

NN. SHUSHUFINDI 35.

Samples were taken in three pits, two water wells and one spring. A total of seven samples were taken: two soil in pit 2, one soil in each of pits 4 and 3, one of sediment to the northeast of pit 3, two groundwater samples from wells in the north of pit 3 and northeast of pit 4. TPH and PAHs were analyzed in sediment and soil samples, while TPH and Barium were analyzed in water samples. Laboratory results indicated that in pit 2 and 3, there were TPH values that exceed the limits established by RAOHE, while in pit 4 this contaminant appears. It was also established that in pit 2 there are PAH concentrations that do not comply with the limits set by TULAS.

OO. SHUSHUFINDI 02.

A pit with evidence of contamination was located. Four soil samples were taken from this pit in which TPH and PAHs were analyzed. Laboratory results showed that the TPH concentration has values that exceeded the limits established by RAOHE.

PP. SHUSHUFINDI 33.

There are two pits in which samples were taken: two soil samples in pit 2 and a water sample to the north, a soil sample to analyze metals which was sent to CORPLAB from pit 1, and a water sample from a well in the southeast of this pit. TPH and PAHs were analyzed in the soil samples of pit 2, while THP and Barium were analyzed in the water sample. Based on the results, TPH concentrations in the soil of pit 2 were greater than the limits set by TULAs, while the water sample in the southeast of pit 1 indicates the presence of this contaminant in the water.

QQ. SHUSHUFINDI 32.

An open pit of water was located, and a sediment sample was taken. TPH and PAHs were analyzed. Based on the results of laboratory tests, it was established, that TPH concentrations in the sediment exceed the limits set by RAOHE.

RR. GUANTA STATION.

The presence of two pits was observed through aerial photographs and fieldwork in the station, and a sample was taken from the pit identified as PIT 1. TPH and PAHs were analyzed.

SS. SHUSHUFINDI 43 WELL

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The presence of two pits was observed. A total of five samples were taken in these sites: four samples from pit 1, and one sample from pit 2. TPH and PAHs were analyzed in all the samples. Laboratory results showed that TPH concentrations in pit 1 do not to comply with the limits established by RAOHE, while in pit 2 the value exceeds the limit set forth by Fragile Ecosystems provided in the regulation herein mentioned.

8. ADDITIONAL SAMPLES

To complete the information, an additional and extended collection of soil and water samples was carried out from the following sites:

Field	Site
Lago Agrio	Lago Agrio-20
Shushufindi	Shushufindi-61
Auca	Auca-04
Yuca	Yuca-03
Sacha	Sacha-90

APPENDIX L: CABRERA REPORT APPENDIX D

A REVIEW OF ECUADOR'S ENVIRONMENTAL QUALITY STANDARDS

Por: Equipo Técnico del Ing. Richard Cabrera
como parte del
EXAMEN PERICIAL

24 de Marzo del 2008

1. INTRODUCTION

The government of Ecuador has established environmental standards which specify the permissible concentrations of toxic substances in environmental media such as soil and water. These standards, and the environmental laws which establish them, are intended to protect the health of the nation's people and ecosystems from contamination.

This document compares the Ecuadorian standards for toxic substances in water and soil with similar limits established by other countries, states, and international organizations. The comparison shows that the environmental standards of Ecuador are similar to those of other countries, states, and international organizations, as demonstrated in the following examples. Therefore, it is reasonable to use the Ecuadorian standards to assess the impacts of contamination and the need for remediation in the Concession.

2. ENVIRONMENTAL STANDARDS FOR THE PROTECTION OF WATER AND SOIL

Tables 1 and 2 list all of the relevant Ecuadorian environmental standards for soil and water, respectively. Additional details are provided below.

2.1. Environmental standards of other entities

Like Ecuador, other legal entities including nations, states, and international organizations have established environmental regulations to protect people and the environment. Examples of such entities include: the European Community and its member nations, the United States and its states, Canada and its provinces, and the United Nations, through the World Health Organization. In this section, the soil and water protection standards of Ecuador are compared to the standards of other entities.

2.2. Soil quality standards

There are two primary sets of Ecuadorian soil standards, as shown in Table 3. Decreto No. 1215, Tabla 6, Anexo 2 covers the permissible limits for screening and remediation of contaminated soils for all phases of the petroleum industry, including service stations. There are different standards for areas of agricultural use, industrial use, and sensitive

Table 1. Ecuador standards for soil.

PARÁMETRO	Decreto No. 1215. Tabla 6. Anexo 2. *Límites permisibles para la identificación y remediación de **suelos** contaminados en todas las fases de la industria hidrocarburífera, incluidas las estaciones de servicios.* **(mg/kg)**			Decreto No. 3516. Libro VI. Anexo 2. Tabla 3. **Suelos Agrícolas (mg/kg)**
TPH suelo	1000	2500	4000	n/d
HAPs suelo	<1	<2	<5	<2
Benzo a Pireno suelo	n/d	n/d	n/d	0.1
Naftaleno suelo	n/d	n/d	n/d	0.1
Cadmio suelo	<1	<2	<10	2
Niquel suelo	<40	<50	<100	50
Plomo suelo	<80	<100	<500	100
Bario suelo	n/d	n/d	n/d	750
Zinc suelo	n/d	n/d	n/d	200
Cromo suelo	n/d	n/d	n/d	65
Cromo VI suelo	n/d	n/d	n/d	0.4
Vanadio suelo	n/d	n/d	n/d	130
Mercurio suelo	n/d	n/d	n/d	0.8
Cobre suelo	n/d	n/d	n/d	63
Benceno suelo	n/d	n/d	n/d	0.05
Benzo-a-antraceno suelo	n/d	n/d	n/d	0.1
Tolueno suelo	n/d	n/d	n/d	0.1
Etil-benceno suelo	n/d	n/d	n/d	0.1
Xileno suelo	n/d	n/d	n/d	0.1
Pireno suelo	n/d	n/d	n/d	0.1

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Table 2. Ecuadorian standards for water.

PARÁMETRO	Decreto No. 1215. Anexo 3. Tabla 10. *Parámetros adicionales y límites permisibles para **aguas** y descargas líquidas en la*			Decreto No. 3516.Libro VI. Anexo 1. **Aguas**
TPH agua	n/d	325	0.5	n/d
HAPs agua	n/d	n/d	0.0003	n/d
Benzo a Pireno agua	n/d	0.026	n/d	0.00001
Naftaleno agua	n/d	35	n/d	n/d
Cadmio agua	<0.1	3.2	0.001	0.001
Niquel agua	<2.0	45	0.025	0.025
Plomo agua	n/d	45	n/d	0.05
Bario Agua	n/d	338	1	1
Zinc agua	n/d	433	0.18	5
Cromo agua	n/d	16	0.05	n/d
Cromo Vi agua	n/d	n/d	n/d	0.05
Vanadio agua	n/d	n/d	n/d	0.1
Mercurio agua	<0.01	0.18	0.0002	0.001
Cobre agua	n/d	45	0.02	1
Benceno agua	n/d	15	n/d	0.01
Benzo-a-antraceno agua	n/d	0.25	n/d	n/d
Fenantreno agua	n/d	2.5	n/d	n/d
Fluoranteno agua	n/d	0.5	n/d	n/d
Indeno-123cd-pireno agua	n/d	0.025	n/d	n/d
Solidos Disueltos Totales agua	n/d	n/d	n/d	500

ecosystems. In addition, Decreto No. 3516, Libro VI, Anexo 2, Tabla 3 defines standards for specifically for agricultural soils.

Table 3: Ecuador soil quality standards

Name	Definition	Applicability
Decreto No. 1215. Tabla 6. Anexo 2.	Límites permisibles para la identificación y remediación de suelos contaminados en todas las fases de la industria hidrocarburífera, incluidas las estaciones de servicios.	Ecosistemas sensibles Uso agrícola Uso industrial
Decreto No. 3516. Libro VI. Anexo 2. Tabla 3.	Suelos Agrícolas.	Suelos Agrícolas

Table 4 contains examples of Ecuadorian soil standards for some key contaminants in the Concession compared to values (highest and lowest) from other nations and organizations. A full table showing all of the standards reviewed and summarized in this table is located in Appendix A.

Table 4: Comparison of Ecuadorian and other soil quality standards, ppm

Ecuadorian soil standards			Summary of non-Ecuadorian values	
Parámetro	**Limit**	**Decreto / tabla**	**Lowest non-Ecuadorian standard (source of standard)**	**Highest non-Ecuadorian standard (source of standard)**
Cadmio	<1	a	0.00222 (U.S. EPA R5 RCRA)	140 (U.S. EPA Eco-SSL for soil invertebrates)
Cromo	65	b	0.4 (Total Cr) (U.S. EPA R5 RCRA)	220 (Soluble Cr III) (Netherlands integrated SRCs)
Cromo VI	0.4	b	0.4 (CCME EQGs)	81 (U.S. EPA Eco-SSL for mammalian wildlife)
Niquel	<40	a	13.6 (U.S. EPA R5 RCRA)	280 (U.S. EPA Eco-SSL for soil invertebrates)
Zinc	200	b	6.62 (U.S. EPA R5 RCRA)	350 (Netherlands integrated SRCs)
Benceno	0.05	b	0.0068 (CCME EQGs for the protection of human and ecological health)	1.1 (Netherlands integrated SRCs)
Benzo-a-Pireno	0.1	b	0.1 (U.S. EPA RAGS; CCME EQGs)	7 (Netherlands integrated SRCs)
Naftaleno	0.1	b	0.0994 (U.S. EPA R5 RCRA)	17 (Netherlands integrated SRCs)
HAPs	<1	a	1 (U.S. EPA RAGS)	LMW: 100 (U.S. EPA Eco-SSLs for the protection of mammalian wildlife) HMW: 18 (U.S. EPA Eco-SSLs for the protection of soil invertebrates)

RCRA = Resource Conservation and Recovery Act.
a. Decreto No. 1215. Tabla 6. Anexo 2.
b. Decreto No. 3516. Libro VI. Anexo 2. Tabla 3. Suelos Agrícolas.

For TPH, Ecuador's standard for TPH in soil is 1,000 ppm for the protection of sensitive ecosystems, 2,500 ppm for agricultural uses, and 10,000 ppm for industrial uses. For comparison, there are no U.S. government standards for TPH since TPH is regulated by states and not the federal government. Recently many of the states have been moving to soil standards that are based more on some of the individual chemicals in petroleum rather than on TPH. However, a survey of U.S. States' petroleum hydrocarbon cleanup standards lists several states that had TPH regulations in effect in 2003, when the most recent survey was conducted (AEHS, 2008). Examples of U.S. states' regulations for TPH or TPH for waste oil in soil are shown in Table 5. Although some of these states may have replaced these TPH standards with individual chemical standards since 2003, the values in the table at least provide a valid comparison for standards that are based on TPH.

Table 5: Examples of TPH soil standards for selected U.S. states, ppm

State	Analyte	Standard value	Standard type
Alabama	TPH (waste oil)	100	Alabama Cleanup Standards for Hydrocarbon Contaminated Soil
Colorado	TPH	500	Colorado Clean-up Standards for Hydrocarbon Contaminated Soil and Groundwater
Florida	TRPH	340	Florida Cleanup Standards for Hydrocarbon Contaminated Soil
Iowa	TEH	3,800	Iowa Action Levels for Soils and Groundwater
Maryland	TPH	230	Maryland Cleanup Standards for Hydrocarbon Contaminated Soil
Minnesota	TPH (waste oil, DRO)	10	Minnesota Cleanup Standards for Hydrocarbon Contaminated Soil- Action Level
Missouri	TPH	50	Missouri Cleanup Standards for Hydrocarbon Contaminated Soil (standard varies, based on site-specific features such as soil qualities and proximity to groundwater)
Nevada	TPH (waste oil)	100	Nevada Cleanup Standards for Hydrocarbon Contaminated Soil- Action and Cleanup Levels
Oregon	TPH (waste oil)	100	Oregon Cleanup Standards for Hydrocarbon Contaminated Soil
Rhode Island	TPH (waste oil)	500 to 1,000	Rhode Island Standards for Hydrocarbon Contaminated Soil Direct Exposure Criteria (Residential)
South Dakota	TPH (waste oil)	500	South Dakota Cleanup Standards for Hydrocarbon Contaminated Groundwater, human health protection
Tennessee	TPH (waste oil)	100	Tennessee Cleanup Standards for Hydrocarbon Contaminated Soil- Action and Cleanup Levels
Wyoming	TPH (waste oil, DRO)	2,300	Wyoming Clean-up Standards for Hydrocarbon Contaminated Soil, Action and Cleanup Levels

TEH: Total extractable hydrocarbon.
TRPH: Total residual petroleum hydrocarbons.
Source: AEHS, 2008.

The values in the table range from 10 ppm TPH, which is the soil cleanup standard in Minnesota, to a maximum of 3,800 ppm TPH in Iowa. Of the 13 values listed in the table, 10 are 500 ppm or lower. Therefore, the environmental standards in the U.S. for TPH in soil tend to be lower than the Ecuador standards. This may mean that the Ecuador standards are not protective enough, and that TPH concentrations less than the standard of 1,000 ppm may still pose a problem.

2.3. Water quality standards

There are three primary sets of Ecuadorian water quality standards, shown in Table 6. Decreto No. 1215, Anexo 3, Tabla 10 applies to waters and discharged liquids of the petroleum industry. Decreto No. 3516, Libro VI, Anexo 1, Tabla 5 applies to groundwater in areas where the soil has less then 25% clay content and less 10% organic matter. Tabla 3 of the same document applies to cold fresh water, for the protection of plants and animals, and Tabla 2 applies to water for drinking or domestic use which requires only disinfection.

Table 7 contains examples of Ecuador water quality standards for key contaminants in the Concession, with summary standards (highest and lowest) of other nations and international organizations. The values shown are the lowest of all the potentially applicable standards for each nation and organization. Appendix B contains a full list of all of the water quality standards that were consulted. The values in the table show that the

Ecuador standards are consistent with standards from other countries or other organizations.

Table 6: Categories of water quality standards

Name	Definition
Decreto No. 1215. Anexo 3. Tabla 10	Parametros adicionales y limites permisibles para aguas y descargas liquidas en la exploracion, produccion, industrializacion, transporte, almacenamiento y comercializacion de hidrocarburos y sus derivados.
Decreto No. 3516. Libro VI. Anexo 1. Aguas	Tabla 5. Criterios referenciales de calidad para aguas subterráneas, considerando un suelo con contenido de arcilla entre (0-25,0) % y de materia orgánica entre (0-10,0)%.
	Tabla 3. Criterio para preservación de Flora y Fauna (Agua Dulce Fria).
	Tabla 2. Limites máximos permisibles para aguas de consumo humano y uso doméstico que únicamente requieran desinfección.

Table 5: Comparison of Ecuadorian and other water quality standards in ppm

Ecuadorian standards			Non-Ecuadorian standards	
Parámetro	**Limit**	**Decreto / tabla**	**Lowest non-Ecuadorian standard (source of standard)**	**Highest non-Ecuadorian standard (source of standard)**
Cadmio	0.001	a	Total Cd = 0.000017 (Canada: EQGs)	0.005 (OECD: drinking water and USA: MCL for drinking water)
Cromo VI	0.05	b	Dissolved = 0.001 (Canada: EQGs)	Dissolved = 0.011 (USA: chronic value for the protection of aquatic life)
Cromo	0.016	c	Total Cr = 0.0089 (Canada: EQGs)	Total Cr = 0.18 (USA: NAWQC)
Niquel	0.025	a	0.02 (OECD: Drinking water, inland surface waters, and other inland waters)	4.6 (USA: Human Health, based on fish consumption)
Zinc	0.18	d	Total Zn = 0.030 (Canada: EQGs)	26 (USA: Human Health, based on fish consumption)
TPH	0.325	c	Narrative standards: No objectionable taste or odor; no film on surface of water, no coatings on the beds of watercourses and lakes; no detectable hydrocarbon taste to fish/shellfish flesh, no harmful effects to fish/shellfish or their larvae. (WHO: Drinking Water; OECD: Protection of Fish and Shellfish Waters)	n/a
Benceno	0.01	b	0.001 (WHO: drinking water)	0.370 (Canada: EQGs)
Benzo a Pireno	0.00001	c	0.0000038 (USA: Human Health, based on consumption of fish and water)	0.007 (WHO: drinking water)
Naftaleno	0.035	c	0.0011 (Canada: EQGs)	0.079 (Netherlands, NEL)
HAPs	0.0003	d	Sum of specified individual PAHs = 0.0001 Sum of PAHs applies to the sum of the following substances: Benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, and indeno(1,2,3-cd)pyrene. (OECD: Drinking Water).[1]	n/a

a. Decreto No. 3516, Libro VI, Anexo 1. Tabla 2, Tabla 3.
b. Decreto No. 3516, Libro VI, Anexo 1. Tabla 2.
c. Decreto No. 3516, Libro VI, Anexo 1. Tabla 5.
d. Decreto No. 3516, Libro VI, Anexo 1. Tabla 3.

[1] OECD regulations contain additional standards for individual PAHs and combinations of PAHs for which Ecuador has no standards.

The WHO does not have a numeric standard for TPH in water. Instead, the standard is that there should be no detectable or objectionable taste or odor due to TPH (WHO, 2006). They state that health effects are unlikely if TPH cannot be tasted or smelled in water since the thresholds for objectionable taste and odor for typical TPH components are extremely low. The European Union also has narrative standards that there should be no oil film on the surface or bed of waterbodies, and that petroleum hydrocarbon concentrations should not be high enough to harm fish or shellfish or cause objectionable tastes in these organisms (European Union, 2006a, 2006b).

As is the case for soils, in the U.S. petroleum hydrocarbons in water are increasingly being regulated on the basis of individual chemicals or fractions rather than simply as TPH. The same survey of U.S. states cited above also provides information on TPH-based water quality regulations that were in effect in 2003 (Table 8). For comparison, Ecuador's standard for TPH in water is 0.325 ppm, from Decreto No. 3516, Libro VI, Anexo 1, Tabla 5. The values in the table show that the Ecuador standard falls within the range of the other standards.

Table 8: Examples of TPH groundwater standards for selected U.S. states, ppm

State	Analyte	Standard value	Standard type
Florida	TRPH	5	Florida Cleanup Standards for Hydrocarbon Contaminated Groundwater
Indiana	TPH (waste oil)	1	Indiana Cleanup Standards for Hydrocarbon Contaminated Groundwater; Action Level and Cleanup Level
Iowa	TEH	1.2	Iowa Action Levels for Soils and Groundwater
Missouri	TPH	10	Missouri Cleanup Standards for Hydrocarbon Contaminated Groundwater, for groundwater and potable groundwater
South Dakota	TPH (waste oil)	0.1	South Dakota Cleanup Standards for Hydrocarbon Contaminated Groundwater; for potential drinking water (within the "influence" of a wellhead)
Tennessee	TPH (waste oil)	0.1	Tennessee Cleanup Standards for Hydrocarbon Contaminated Groundwater- Action and cleanup levels
Wyoming	TPH (waste oil, DRO)	1.1	Wyoming Cleanup Standards for Hydrocarbon Contaminated Groundwater

Source: AEHS, 2008.

3. CONCLUSIONS

Ecuadorian environmental regulations are similar in type, scope, and intent to those of other nations, states, and international organizations. Water quality regulations in Ecuador are set up to protect water on the basis of multiple potential uses, such as for drinking water and for the protection of plants and animals. As seen in Appendices A and B, these categories are identical to or very similar to those of other entities. Soil regulations are also set up for the remediation and protection of soils to provide for a range of potential soil uses, including industrial, agricultural, and ecosystem uses.

Ecuadorian numerical standards for the protection of soil and water are generally similar to those of other nations, states, and international organizations. The concentrations of metals, PAHs, and permitted in soil and water are similar to those of other nations, states, and organizations. In nearly every case, the Ecuadorian standards fall within the range of standards established by the international community, and are always within a similar order of magnitude. The Ecuador standards for TPH in soil are higher than many similar kinds of standards from U.S. states, and thus may not be fully protective.

Therefore, Ecuador environmental standards for soil and water quality, which have been established to protect the health of the nation's people and ecosystems, are consistent with those established by other countries or organizations. Based on this assessment it is reasonable to rely on the Ecuador standards as indicators of soil or water contamination that is excessive and causes adverse impacts to people or the environment.

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APPENDIX A. A REVIEW OF SOIL QUALITY STANDARDS

A REVIEW OF ECUADOR'S ENVIRONMENTAL QUALITY STANDARDS

Table A.1: A review of soil quality standards (ppm)

Parámetro	Lowest Ecuador standard	US EPA						Canadian Environmental Quality Guidelines		Canadian Environmental Quality Guidelines[2]		Netherlands Integrated SRCs
		Eco-SSLs				Region 4 Superfund risk guidance	Region 5 RCRA guidance	Agricultural land	Residential/ parkland	Fine soil, protection of human and ecological health	Coarse soil, agricultural and residential/ parkland topsoils	
		Plants	Soil invertebrates	Avian wildlife	Mammalian wildlife							
Cadmio	<1	32	140	0.77	0.36	1.6	0.00222	1.4	10			13
Cromo	65			26 (Cr III)	34 (Cr III)	0.4	0.4 Cr^{+3} (total)	64 (Total Cr)	64 (Total Cr)			220 (Soluble Cr III)
Cromo VI	0.4			NA	81			0.4	0.4			78
Niquel	<40	38	280	210	130	30	13.6	50	50			100
Zinc	200	160	120	46	79	50	6.62	200	200			350
TPH	1000											
Benceno	0.05					0.05	0.255			0.0068	0.0095	1.1
Benzo-a-Pireno	0.1					0.1	1.52	0.1	0.7			7
Naftaleno	0.1					0.1	0.0994	0.1	0.6			17
HAPs	<1		LMW: 29, HMW: 18		LMW: 100, HMW: 1.1	1						

LMW: low molecular weight.
HMW: high molecular weight.
Sources: Lijzen et al., 2001; U.S. EPA, 2001, 2003, 2005a, 2005b, 2005c, 2007a, 2007b; CCME, 2003, 2005.

[2] 2005 update.

APPENDIX B. A REVIEW OF WATER QUALITY STANDARDS

A REVIEW OF ECUADOR'S ENVIRONMENTAL QUALITY STANDARDS

Table B.1: A review of water quality standards (ppm)

Ecuador		WHO, 2006	OECD				
			Fish protection	Shellfish protection	Drinking water	Surface water as a source for drinking water[a]	
Parámetro	Limit	Drinking water				Inland surface waters[b]	Other inland waters[b]
Cadmio	0.001	0.003		g	0.0050	</ = 0.00008[f] at water hardness <40 mg $CaCO_3$/l 0.00008[f] at water hardness 40 to <50 mg/l 0.00009[f] at hardness 50 to <100 mg/l 0.00015[f] at water hardness 100 to <200 mg/l 0.00025[f] at water hardness >/ = 200 mg/l	0.0002[f]
Cromo VI	0.05						
Cromo	0.016	0.05[h]		g	0.0500		
Niquel	0.025	0.07		g	0.0200	0.02[f]	0.02[f]
Zinc	0.18	j	</ = 1.0[h] at a hardness of 100 mg/l. (0.3 mg/l at hardness = 10 to 2.0 mg/l at hardness = 500)	g			
TPH	0.325	k	l	m			
Benceno	0.01	0.01 (carcinogenic)			0.001	0.01	0.008
Benzo a Pireno	0.00001	0.0007			0.00001	0.00005	0.00005
Naftaleno	0.035					0.0024	0.0012
HAPs	0.0003			m	0.0001[n]	o	o

a. Provisional.
b. Annual Average Environmental Quality Standard.
c. No-effect levels.
d. This is a water concentration protective of human health where people consume both water and aquatic organisms from the affected water body.
e. This is a water concentration protective of human health where people consume aquatic organisms but not the water from the affected water body.
f. Dissolved.
g. Metals: the concentration of each substance in the shellfish water or in the shellfish flesh must not exceed a level which gives rise to harmful effects on the shellfish and their larvae. The synergistic effects of these metals must be taken into consideration.
h. Total.
i. This value was calculated on the basis of a water hardness of 100 mg/l $CaCO_3$. Refer to http://www.epa.gov/waterscience/criteria/wqcriteria.html for guidance on calculating the values of hardness dependent metals where water hardness is greater or less than 100 mg/l $CaCO_3$.
j. Not of health concern at concentrations normally observed in drinking water.
k. Petroleum products: Taste and odor will in most cases be detectable at concentrations below those concentrations of concern for health, particularly with short-term exposure.
l. Petroleum products must not be present in water in such quantities that they form a visible film on the surface of the water or form coatings on the beds of watercourses and lakes, impart a detectable hydrocarbon taste to fish, or produce harmful effects in fish.
m. Hydrocarbons must not be present in the shellfish water in such quantities as to produce a visible film on the surface of the water and/or a deposit on the shellfish, or have harmful effects on the shellfish.
n. Summary standards for PAHs (OECD drinking water): Sum of PAHs applies to the sum of the following specific substances: Benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, and indeno(1,2,3-cd)pyrene.

A REVIEW OF ECUADOR'S ENVIRONMENTAL QUALITY STANDARDS

Table B.1: A review of water quality standards (ppm) (cont.)

Ecuador		Canada, CCME	Netherlands	USA					
				National ambient water quality criteria/ final chronic value	Great Lakes Initiative Tier II, secondary chronic values	Aquatic life, chronic	Human health		Drinking water (MCL)
Parámetro	Limit	Environmental quality guidelines, freshwater aquatic life	NELs[c]				Water plus organism[d]	Organism only[e]	
Cadmio	0.001	0.000017[a,h]		0.001[h]		0.00025[f,i]			0.005
Cromo VI	0.05	0.001				0.011[f]			
Cromo	0.016	0.0089[a,h] (Cr III)		0.18[h]		0.074[f,i] (Cr III)			0.01[h]
Niquel	0.025	0.025 to 0.15		0.16		0.052[f,i]	0.61	4.6	
Zinc	0.18	0.030[h]		0.1[h]		0.120[f,i]	7.4	26	
TPH	0.325								
Benceno	0.01	0.370			0.130		0.0022	0.051	0.005
Benzo a Pireno	0.00001	0.000015	0.000156		0.000014		0.0000038	0.000018	0.0002
Naftaleno	0.035	0.0011	0.079		0.012				
HAPs	0.0003								

a. Provisional.
b. Annual Average Environmental Quality Standard.
c. No-effect levels.
d. This is a water concentration protective of human health where people consume both water and aquatic organisms from the affected water body.
e. This is a water concentration protective of human health where people consume aquatic organisms but not the water from the affected water body.
f. Dissolved.
g. Metals: the concentration of each substance in the shellfish water or in the shellfish flesh must not exceed a level which gives rise to harmful effects on the shellfish and their larvae. The synergistic effects of these metals must be taken into consideration.
h. Total.
i. This value was calculated on the basis of a water hardness of 100 mg/l $CaCO_3$. Refer to http://www.epa.gov/waterscience/criteria/wqcriteria.html for guidance on calculating the values of hardness dependent metals where water hardness is greater or less than 100 mg/l $CaCO_3$.
j. Not of health concern at concentrations normally observed in drinking water.
k. Petroleum products: Taste and odor will in most cases be detectable at concentrations below those concentrations of concern for health, particularly with short-term exposure.
l. Petroleum products must not be present in water in such quantities that they form a visible film on the surface of the water or form coatings on the beds of watercourses and lakes, impart a detectable hydrocarbon taste to fish, or produce harmful effects in fish.
m. Hydrocarbons must not be present in the shellfish water in such quantities as to produce a visible film on the surface of the water and/or a deposit on the shellfish, or have harmful effects on the shellfish.
n. Summary standards for PAHs (OECD drinking water): Sum of PAHs applies to the sum of the following specific substances: Benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, and indeno(1,2,3-cd)pyrene.
o. Summary standards for PAHs (OECD inland surface waters as a source for drinking water): there are summary standards for individual PAHs for which Ecuador has no standards; these are not listed here.
Sources: Van Leeuwen et al., 1992; Suter and Tsao, 1996; European Union, 1998, 2006a, 2006b, 2006c; CCME, 1999; WHO, 2006; U.S. EPA, 2008.

APPENDIX M: CABRERA REPORT APPENDIX J

ANEXO J: ECOLOGICAL IMPACTS FROM CONTAMINATION IN THE NAPO CONCESSION

Por: Equipo Técnico del Ing. Richard Cabrera
como parte del
EXAMEN PERICIAL

24 de Marzo del 2008

This annex is an assessment of the ecological impacts caused by contamination in the Concession. The purpose is to evaluate and describe the impacts of the contaminants on the ecology of the Concession using standard approaches and methods.

1. APPROACH

This assessment of environmental impacts in the Napo Concession was conducted using standard methods for identifying and characterizing risks to plants and wildlife, referred to as ecological receptors, from contamination (U.S. EPA, 1998). These methods include a description of the Concession ecology, development of a conceptual model, selection of contaminants that will be analyzed, identification of exposure routes, identification of toxicity levels, and analysis of environmental data.

2. ECOLOGY OF CONCESSION AREA

The zone of the Concession covers approximately 400,000 hectares of the eastern slope of the Andes Mountain range in northeastern Ecuador's Oriente District. The Concession area varies in elevation between 200 and 350 meters above sea level with gently sloping land and flat valleys. This region receives heavy rainfall that ranges from 2,000 to 5,000 mm annually (Agra, 1993). There are many large and small rivers in the region. Major rivers include the Rio Napo, Rio Coca, Rio San Miguel, and Rio Aguarico, which flow east toward the Amazon River. There are also many smaller streams and permanent and temporary ponds throughout the Concession.

The Concession is in the Amazon ecological region. This region has a very high diversity of fish and wildlife (Agra, 1993). There are 1,578 bird species that have been identified in continental Ecuador (Parker et al., 1996; Ridgely et al., 1998, as cited in Gallo, 2007). Of these, 695 species potentially inhabit the Concession area. There are also 191 mammal species that can potentially inhabit the Concession area (Tirira, 1999, as cited in Gallo, 2007). The most diverse mammal groups are Chiroptera (bats) and Rodentia. There area 464 amphibian and 405 reptile species inhabiting the Amazon region (Coloma et al., 2007, as cited in Gallo, 2007). The most diverse amphibian families are Hylidae, Leptodactylidae Dendrobatidae, and Colubridae, and the most diverse reptile families are Gymnophthalmidae and Polychrotidae. Aquatic biota are also diverse with hundreds of fish species, most belonging to the Characiformes and Siluriformes orders. Although less studied, freshwater macroinvertebrates are also diverse in the Concession area.

In addition to natural ecological communities, human disturbances have provided habitat for flora and fauna that would otherwise not be present. For example, Gallo (2007) found that many of the species sampled in the Concession area are adapted to disturbed or agricultural ecosystems. The area supports flora and fauna that are adapted to habitat disturbances such as those caused by oil production activities, deforestation, pastures and coffee plantations, and road building. Examples include: *Bos taurus* (domestic cow), *Sus scrofa domestica* (domestic pig), *Equus asinus* and *E. caballus* (donkey and horse), *Mus musculus* (house mouse) and *Rattus rattus* (rat).

3. TOXICITY ASSESSMENT

A conceptual model was used to identify the sources of contamination, ecological receptors, and routes of exposure. This model was used to select the types of contaminants that pose the greatest risk to the Concession ecosystem. Once contaminants were identified, the fate and transport of these contaminants the exposure to ecological receptors was assessed. Next, contaminant concentration data from the Concession were compared to toxicity benchmark levels to determine if concentrations in the Concession are toxic. Finally, the conclusions from this assessment are compared to results from biological surveys conducted in the Concession.

3.1 Conceptual model

The main body of the report describes the sources, pathways, and fate of the different contaminants that Texpet has released into the environment of the Concession. With respect to the primary sources of the contamination we have are crude oil, which contains petroleum hydrocarbon compounds (e.g., benzene, polycyclic aromatic hydrocarbons) and metals, formation water, and drilling muds and other drilling additives. Crude oil, formation water, and drilling additives were deposited into open pits and/or discharged into the environment in the vicinity of the oil wells. The formation water was released primarily from the stations after it was separated from the crude oil, although there are also thousands of kilometers of crude oil pipelines from which numerous spills have occurred as described in annex I.

Figure 1 is a conceptual model of sources and exposure routes of contamination in the Concession. Soil contamination can occur from intentional disposal of waste materials, such as pits and the overflow and seepage from them, and from spills. Surface water can be contaminated from the same sources as soil and from the disposal of produced water. Air can be contaminated from burning of oily wastes (such as flare pits) and from gas flares (Agra, 1993). All of the air contamination pathways can also be sources of soil and water as aerial deposition. Once released into soils, surface water, sediments, groundwater, and air, contaminants can potentially expose ecological receptors such as fish, wildlife, and birds.

Figure 1: Conceptual diagram for the Concession study area

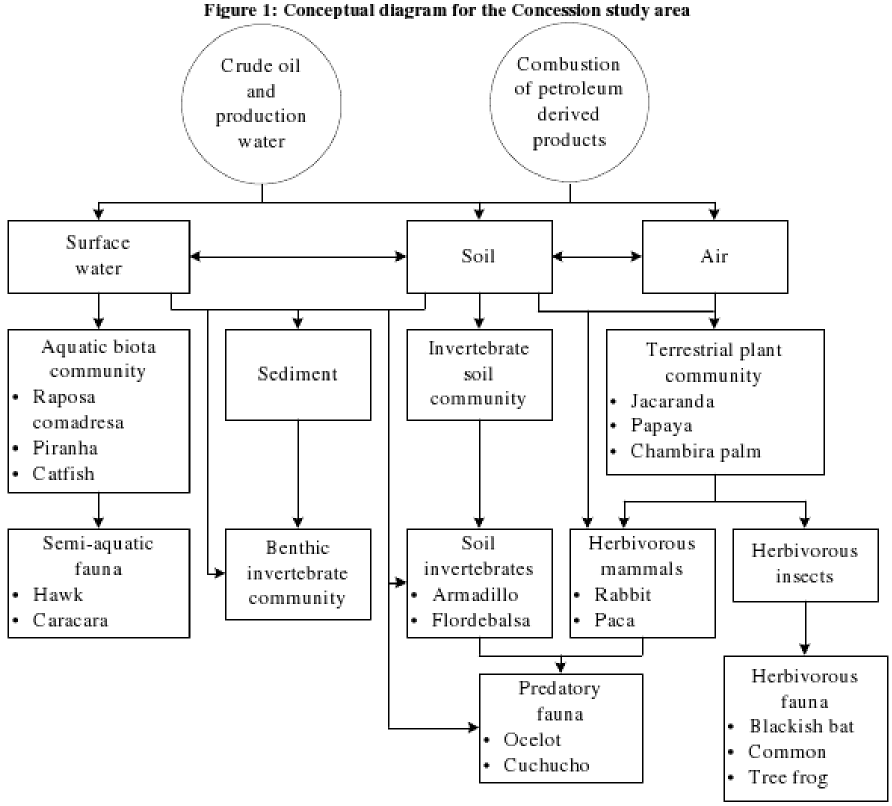


Figure 1. Conceptual model identifying potential sources of contamination, exposure routes, and ecological receptors in the concession area. Listed ecological receptors are only a small representation of the total diversity found in the Amazon ecological region.

3.2 Identification of key contaminants

Based on the contaminant sources, we identified the most important chemicals that could cause toxicity to the ecology of the region.

Crude oil is complex mixture of hundreds of different constituents. A list of some of the toxic constituents of crude oil is provided in Table 1 (Irwin et al., 1997; data collected for the litigation).

Table 1: Sample of the toxic crude oil constituents (Irwin et al., 1997; data collected for the litigation)

Volatile organic compounds	Polycyclic aromatic hydrocarbons	Inorganics
Benzene	Acenaphthene	Antimony
Ethyl benzene	Acenaphthylene	Arsenic

Toluene	Anthracene	Barium
Xylenes	Benz(a)anthracene	Beryllium
	Benzo(a)pyrene	Cadmium
	Benzo(b)fluoranthene	Chromium
	Benzo(c)pyrene	Cobalt
	Benzo(g,h,i)perylene	Copper
	Benzo(k)fluoranthene	Lead
	Chrysene	Mercury
	Dibenz(a,h)anthracene	Molybdenum
	Naphtalene	Nickel
	Fluoranthene	Selenium
	Fluorene	Silver
	Indeno(1,2,3-cd)pyrene	Titanium
	Phenanthrene	Vanadium
	Pyrene	Zinc

Produced water is formation water trapped underground with the crude oil and that comes to the surface along with the crude oil. Formation water can include oils, grease, salt and many dissolved organic and inorganic compounds (DOE, 2004). The salinity of formation water can be very high (greater than sea water) Because formation water is under different pressures and temperatures at depth than at the earth's surface, it can be saturated with otherwise insoluble organic compounds and metals. Table 2 lists the typical constituents of produced water from the Gulf of Mexico and limited data from the Concession.

Table 2: Constituents of produced water from crude oil production (DOE, 2004; data collected for the litigation)

Oil and grease	Triterpanes	Xylenes	Lead
2-Butanone	Ethylbenzene	Aluminum	Manganese
2,4-Dimethylphenol	n-Alkanes	Arsenic	Nickel
Anthracene	Naphthalene	Barium	Titanium
Benzene	p-Chloro-m-cresol	Boron	Zinc
Benzo(a)pyrene	Phenol	Cadmium	Radium 226 and 228
Chlorobenzene	Styrenes	Copper	Chloride
Di-n-butylphthalate	Toluene	Iron	Sulfate

Given the large lists of potential contaminants associated with oil exploitation activities in the concession area, it would be impractical to assess the toxicity of all of the constituents in this report. Therefore, we focused on a few contaminants that are toxic and that ecological receptors are exposed to. It is important to note that there are hundreds to thousands of compounds and elements in crude oil that are potentially toxic. Only focusing on a few contaminants may lead to an underestimation of toxic effects.

In this assessment, we focused on the volatile organic compounds benzene, toluene, ethyl benzene, and xylene (collectively referred to as BTEX), oil as represented by total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAHs), and inorganic constituents such as barium, cadmium, chromium, copper, lead, nickel, vanadium, zinc, and chloride.

3.3 Environmental fate of key contaminants

An important step in assessing the impacts from environmental contamination is to evaluate what happens to the contaminants once they are released into the environment. This is known as the fate of the contaminants. In water, contaminants might evaporate, disperse into the water column, attach to sediment, accumulate in aquatic biota, or experience chemical oxidation and biodegradation (Suess, 1976, as cited in Eisler, 1987). Likewise, contaminants in soils or sediment can accumulate into biota, volatilize, dissolve into water, be transported with surface water, or degrade (Novotny, 2003). During bacterial degradation, pollutants might be volatilized, as in the case of some metals, or decomposed into simpler compounds, as observed in some hydrocarbons. These processes are all dependent on the environmental conditions or soil composition at the site and characteristics of the contaminants being evaluated. Therefore, it is important to investigate general characteristics of environmental media within the concession.

The quality of Concession surface waters in the Shushufindi region has been characterized by Villacreces (2000). The author reported an average temperature of surface waters of 27.7°C, which did not vary considerably throughout the year. This temperature regime is ideal for maintaining a stable population of aquatic flora and fauna. The average pH value was 7.1, and ranged from 6.3 to 7.8. Dissolved oxygen is an important factor in determining fate of contaminants in water and often drives reduction and oxidation processes in sediments. Dissolved oxygen measurements were variable among sampling locations and ranged from 2.0 to 6.4 mg/L with a mean of 4.7 mg/L. At these low oxygen levels reduction processes in river sediments are most likely dominant.

Characteristics that affect the soils and sediments capacity to adsorb and retain contaminants include organic matter content, surface area of soil particles, and organic acid content (Schlesinger, 1997; Novotny, 2003). Organic matter in soils can bind some contaminants and make them less bioavailable. The amount of soil surface area also can be important in binding contaminants, and soil surface area generally increases as more clay is present.

Rainforest soil is highly affected by chemical weathering. Long periods of intense weathering can remove much of the cations and silicon from the soil profile (Schlesinger, 1997). Soils in the Amazon basin are quite diverse and include areas of fertile alluvial soil, organic histosols, and more-weathered tropical oxisols (Agra, 1993). Kauffman and Creutzberg (1999) characterized soils near the Concession as high in clay content (70-80%), medium in organic carbon (<2%), strongly acidic (pH~2.0), low cation exchange capacity, and high in moisture (15-18%).

Given the characteristics of surface water and soils in the Concession we can generalize which environmental media will be important to investigate for specific contaminants. For example, BTEX compounds are moderately soluble in water, moderately volatile, and have little to no sorption to soils and sediments. Therefore, once they are released they can be transported from release sites in groundwater or surface water, evaporated into the atmosphere, and degraded. Less volatile hydrocarbons, such as PAHs, behave differently. They have low aqueous solubility, low evaporation rates, and high affinity for adsorption on soils and sediments. These hydrocarbons would primarily exist in the soils and sediment at or near release sites and be slowly degraded by microorganisms, because of limited organic carbon content and low dissolved oxygen in soils and sediments. Once released into the environment, metals such as barium, cadmium, chromium, copper, lead, nickel, and zinc would be relatively mobile in soil, potentially exposing aquatic communities. Terrestrial communities would be exposed to metals that high potential to accumulate in soils, such as barium, copper, chromium, and zinc.

Physical processes such as rain runoff can transport contaminants that are adsorbed to soils and sediments. Similarly, surface oil accumulations can also be transported by runoff. Given the frequency and intensity of rain in the Concession, physical transport of contaminants might be substantial. These processes could lead to contamination of aquatic and terrestrial environments far from the original sources.

3.4 Physical effects of spilled oil

In addition to toxicity, plants and animals can also suffer from the physical effects of oil. Most published information on ecological effects of crude oil spills is from observational data, collected after oil tanker spill events. From these studies, birds have been identified as being particularly sensitive to crude oil exposure.

Birds are particularly sensitive to spilled oil because the oil clogs the fine structure of feathers, making them matted and unable to trap air. Oiled feathers decreases water repellency, body insulation, buoyancy in aquatic birds, and ability to fly. If severe, oiled birds can die of starvation or hypothermia. Additionally, oil may be ingested when oiled plumage is preened. Ingesting oil has shown to cause anemia, pneumonia, kidney, and liver damage, decreased growth, altered blood chemistry, and decreased egg production and viability (Overton et al., 1994; as cited in Irwin et al., 1997).

In addition to individual adverse affects, oiled birds can expose developing eggs and young when returning back to nesting sites. Even minute quantities of oil products applied to the surface of eggs have been shown to reduce growth and increase incidence of embryos developing deformities in the eye, brain, bill, and liver (Albers, 1983; Hoffman and Gay, 1981, as cited in Dickerson et al., 2002).

Some research has shown adverse behavioral effects of oil exposure that result in reduced reproductive success. For example, exposure to oil in petrels resulted in a ranges of effects that included abandoning the nesting colony, rejecting to incubate eggs, and rejecting to care for chicks (Meyer et al., 1994; as cited in Irwin et al., 1997).

Although less studied, aquatic and semi-aquatic mammals may also be directly impacted by oil exposure. Similar to birds, a mammals fur coat maintains warmth and buoyancy in the water. This fur traps air that insulates the animal when wet. When exposed to oil, the fur becomes matted and losses its ability to trap air. This increases the chance of hypothermia and decreases buoyancy when in water.

Oil can also smother vegetation and destroy valuable habitat. In terrestrial environments, plants need to respire through their leaves and roots. When covered with oil, respiration and sunlight getting to the leaves can be reduced. In aquatic environments, oil covers the water surface and effectively blocks the exchange of oxygen between water and air. This could lead to anaerobic conditions, in which few aquatic organisms can survive.

In summary, oil spills or accumulation of oil on the ground surface or in water can have immediate detrimental direct physical effects on birds, mammals, and habitat quality. Direct contact with oil can reduce the insulation properties of feathers and fur and contribute to adverse behavioral changes affecting reproductive success. Both terrestrial and aquatic habitats can be smothered by spilled oil by reducing respiration, photosynthesis, and gas exchange.

3.5 Toxicity profiles of contaminants of interest

In this section, the ecological toxicity of the key contaminants is described using published toxicity values (U.S. EPA, 1997). These studies usually report point estimates of exposure that result in adverse affects such as death and reduced growth. Typical point estimates include LC50's and toxicity benchmarks. An LC50 is the concentration at which 50% of the exposed test organisms die after acute (short-term) or chronic (long-term) exposures. Effect concentration for sublethal effects are often identified as the concentrations at which statistically different responses occur compared to unexposed organisms.

Toxicity benchmarks are usually derived from a collection of individual toxicity point estimates. Toxicity benchmarks can be regulatory criteria, cleanup or action levels, or screening level concentrations that represent concentrations at or above which toxicity may occur. For example, water quality criteria are toxicity benchmarks that are intended to protect aquatic organisms. They are based on acute and chronic toxicity data for a wide variety of aquatic organisms. Acute criteria are established for short term exposures and chronic for long term exposures. Since the duration of exposure is directly related to toxicity, acute criteria are usually less protective then chronic criteria. The toxicity of some metals are modified with respect to water hardness. Generally, the toxicity of these metals decreases with increasing water hardness. For simplicity, we normalized these criteria to a hardness of 100 mg/L which is probably similar to Concession waters. If concentrations of contaminants in water are greater then respective water quality criteria then there is risk of toxicity in sensitive aquatic organisms.

Contaminant concentrations in soil that cause adverse affects in ecological receptors are also available. Similar to water quality criteria, if concentrations in soil exceed respective soil toxicity benchmarks there is risk of adverse affects in exposed receptors. Soil benchmarks are based on the estimated exposure to a given toxicant. As such, they are often receptor specific. For example, a root eating mammal would be exposed to more soil contamination then an arboreal seed eating bird.

Table 3 lists point estimates, toxicity benchmarks, and national standards that can be used to characterize risk to aquatic and terrestrial receptors. This assemblage of values potentially encompasses the major receptor groups in the concession (Section 2.1.1).

Table 3: Point estimates, toxicity benchmarks, and national standards for aquatic and soil dwelling receptors used to environmental samples

Contaminant	Water quality (ug/L)			Soil quality (mg/Kg)				
	Ecuador standard	U.S. EPA acute	U.S. EPA chronic	Ecuador standard	Plant (U.S.)	Invertebrates (U.S.)	Avian (U.S.)	Mammal (U.S.)
Benzene	–	5,300	262.0	–	–	–	–	–
Toluene	–	17,500	110.3	–	–	–	–	–
Ethyl benzene	–	32,000	1,800	–	–	–	–	–
Xylene	–	–	2,600	–	–	–	–	–
PAHs (low/high mol. weight)	0.3	–	–	–	–	–	–	–
Total Petroleum Hydrocarbons	500	–	–	1,000	–	–	–	–

Barium	1,000	–	–	–	–	330.0	–	2,000
Cadmium	1.0	2.0	0.25	–	–	–	–	–
Chromium III	50.0	570.0	74.0	–	–	–	26.0	34.0
Chromium VI	–	16.0	11.0	–	–	–	–	–
Copper		13.0	9.0		70	80	28	49
Lead	–	65.0	2.50	–	–	–	–	–
Nickel	25.0	470.0	52.0	–	–	–	–	–
Zinc	180.0	120.0	120.0	–	160.0	120.0	46.0	79.0
Chloride	–	860,000	230,000	–	–	–	–	–

* = Toxicity modified with respect to water hardness, criteria normalized to a hardness of 100 mg/L

References: CEPA, 1993; Rowe et al., 1997; EPA, 1980a, 1980b, 1985, 1988, 1996, 2005a, 2005b, 2005c, 2007

Chronic criterion were not available for BTEX in surface water; therefore, we identified suitable point estimates from literature sources. We considered published toxicological data for aquatic invertebrates, fish, and amphibians to profile chronic BTEX toxicity. Because BTEX refers to at least four closely related compounds we investigated each separately. Fish and amphibians are considered to be most sensitive to benzene exposure (Black et al., 1982, as cited in CEPA, 1993; U.S. EPA, 1980a; Rowe et al., 1997). In chronic benzene exposures, growth was reduced after 168 days in fathead minnow at 262 ug/L (Marchini et al., 1992, cited in Rowe et al., 1997). Toluene's toxicity profile is similar to benzene, in that fish are more sensitive than invertebrates (U.S. EPA, 1980b). In this species growth was reduced after 168 day toluene exposure of 110.3 ug/L (Marchini et al., 1992, cited in Rowe et al., 1997). Interestingly, cyprinid fish species seem to be the most sensitive fish to ethyl benzene exposure, although sublethal effects have been noted at low concentrations in water fleas (*Daphnia magna*) (Rowe et al., 1997). Sublethal chronic effects of xylene exposure have occurred in green algae at 3.9 mg/L (Herman et al., 1990, as cited by Rowe et al., 1997). In summary, we could expect that BTEX will cause chronic toxicity to aquatic biota at concentrations greater than 110 ug/L, with large scale effects occurring at concentrations greater than 5.3 mg/L.

3.6 Comparison of contaminant concentrations in the Concession to toxicity levels

In this section, the data collected for the litigation by the experts are compared to toxicity levels. In some cases, data from other studies are also used (e.g., data for produced water are taken from older studies when produced water was being discharged into streams and rivers).

3.6.1 Surface water

Surface water downstream of stations

Surface water data was obtained for production station outfalls or produced water (Fugro-McClelland, 1992; Agra, 1993; Jocknick et al., 1994), outfall mixing zones (Fugro-McClelland, 1992; Agra, 1993; Villacreces, L.C. 2000), and Concession rivers (Villacreces, L.C. 1998; Fugro-McClelland, 1992; Jocknick et al., 1994; Agra, 1993). Concentration data are available for outfalls, which is the produced water itself, mixing zones in rivers that are a short distance downstream of outfalls, and from rivers farther downstream after the produced water has fully mixed with the river water.

Outfall and mixing zone data show that toxic water is discharged into Concession surface waters. For example, every outfall chloride measurement made at 15 production stations by

Fugro-Mcclelland (1992) was substantially greater than the chronic water quality criterion of 230,000 ug/L and all but one measurement were greater than the acute criterion of 860,000 ug/L. On average, exceedences were approximately 30 times greater than acute chloride criterion. This same trend was seen in the Agra (1993) outfall chloride samples. These results indicate that produced waters are very toxic to aquatic life, and that toxicity would occur very quickly. The water has to be diluted substantially so that concentrations are low enough for aquatic biota to survive in the water.

Mixing zone measurements are more variable then outfall data, but also show similar toxic concentrations of chloride. All mixing zone data from stations, except for Lago Central, were greater than the chronic water quality criterion of 230,000 ug/L. Water downstream of the mixing zones also had high chloride concentrations, but lower then corresponding production station effluent and mixing zone area. The data show that river waters downstream of stations were toxic to aquatic organisms, with chloride criteria exceedences extending as far as 450 meters downstream from the outfalls (Fugro-Mcclelland, 1992). However, samples were not collected at enough locations to determine exactly how far downstream the toxicity was occurring at all of the stations.

The conclusions are similar for TPH, PAHs, and BTEX. TPH was greater than or equal to the Ecuadorian standard (500 ug/L) in all 30 outfall samples measured (Fugro-Mcclelland, 1992; Agra, 1993). Mixing zone TPH measurements were also greater than or equal to the standard at four out of five stations (Fugro-Mcclelland, 1992). The greatest downstream extent of TPH contamination occurred 700 meters downstream of the Sacha Sur station where TPH was measured at a concentration that was 2.4 times greater than the Ecuadorian standard.

Jocknick et al. (1994) collected data on individual hydrocarbon chemicals in production station effluents and downstream of the stations. PAHs were detected in all station samples, and exceeded the Ecuador standard (0.3 ug/L) in the East Sacha station (0.41 ug/L). PAHs were also measured in nine surface water locations used for bathing and fishing. The PAH standard was exceeded in two samples taken near production stations. In one of these samples collected near the North Shushufindi station, PAH was measured five times greater than the standard set to protect aquatic flora and fauna.

BTEX compounds were also measured in the six production water samples analyzed by Jocknick et al. (1994). At these stations, measurements did not exceed acute water quality criteria, but chronic benzene and toluene point estimates were exceeded at North Shushufindi and East Sacha stations. At these stations, total BTEX concentrations were similar to TPH measurements made by Fugro-Mcclelland (1992) and Agra (1993). This indicates that TPH in production station effluents is mostly BTEX, which makes sense since BTEX are the most water soluble hydrocarbon compounds in crude oil.

Surface water throughout the Concession

There is evidence that TPH contamination is common throughout the Concession streams and rivers in addition to areas downstream of stations. In an effort to characterize risk to people using river water, San Sebastian et al. (2001, 2002) measured TPH concentrations in 21 streams and rivers. Six of the 21 samples (28%) contained TPH at concentrations greater than the Ecuadorian TPH standard. These data show that rivers in the Concession were contaminated with oil, even in areas that were not immediately downstream of stations.

Villacreces (1998) collected water samples from 56 stream and river locations within the Concession and analyzed them for cadmium, chromium, copper, nickel, lead, and zinc. Cadmium concentrations were greater than the acute (2.0 ug/L) or chronic (0.25 ug/L) water criteria at 27 of the 56 locations sampled, with a maximum of 11 ug/L in the Rirana and Salaleta rivers (Villacreces, 1998). Acute and/or chronic chromium (VI) water quality criteria were exceeded at 21 of the 26 locations where detected. No samples were greater than the total chromium water quality criteria. Copper was detected in 49 of the 56 samples, and only six samples did not exceed the acute or chronic copper criteria (13 and 9 ug/L, respectively). The highest copper concentrations were collected near the Nanto station (770 ug/L) and in the Tiputini River (640 ug/L). Twenty-eight of the 30 samples analyzed for nickel exceeded the acute or chronic water quality criteria (470 and 52 ug/L, respectively) or the more protective Ecuadorian standard (25 ug/L). Lead was detected in 10 samples. Zinc was detected at most sites, and all measured concentrations were less than the Ecuador standard.

It is important to note that Villacreces (1998) collected samples from a wide selection of locations within the Concession. Little information was provided to definitively link sample locations to oil production impacts. Therefore, it is not clear whether the contamination was the result of oil production or other sources within the Concession.

In summary, the data show that rivers and streams in the Concession are contaminated with petroleum hydrocarbons and metals, and that the concentrations are or were high enough to be toxic to aquatic life. Specifically, the concentrations of chloride, TPH, and BTEX
At and downstream of station discharges of produced water were very toxic to aquatic life during the time that produced water was being discharged. The data show that the toxic effects occurred as far as 750 meters downstream. Moreover, throughout the Concession the concentrations of BTEX, TPH, and metals are toxic to aquatic life. Overall, aquatic life in the Concession are at extreme risk from contamination.

3.6.2 Soil

TPH, barium, copper, chromium, and zinc were identified earlier in this Annex as the soil contaminants of focus. Since most terrestrial organisms are not exposed to soil contaminants that are deep beneath the soil surface, this analysis uses only concentration data from within one meter of the ground surface. We also analyzed pit collected samples separate from non-pit collected samples since some pits have been covered.

Figures 2 and 3 show all measured TPH concentrations for each of the eight oil fields in the Concession. The Ecuadorian standard of 1,000 mg/Kg was exceeded in 36% of the surface soil samples collected from outside of pits and 36% of the samples from pits. The highest TPH concentration in surface soils from outside of pits is from the Aguarico field at 333,262 mg/Kg, and the highest surface soil sample from within pits is 900,000 mg/kg (or 90% TPH) from the Sacha field. The high percentages of the soil samples that exceed the 1,000 mg/Kg standard and the very high concentrations present in some surface soils show that petroleum contamination in surface soils of pits and areas outside of pits poses a high risk to terrestrial life.

Figure 2. Surface soil TPH results for non-pit samples, by campo. Note that the data are shown on a logarithmic scale, which changes how the data appear. The red line shows the Ecuador soil TPH standard of 1,000 mg/Kg.

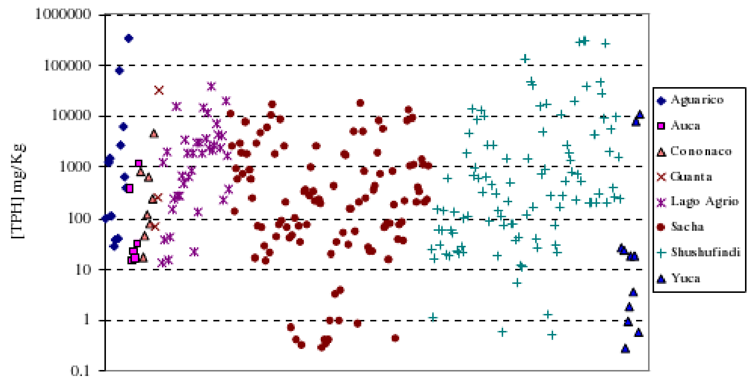
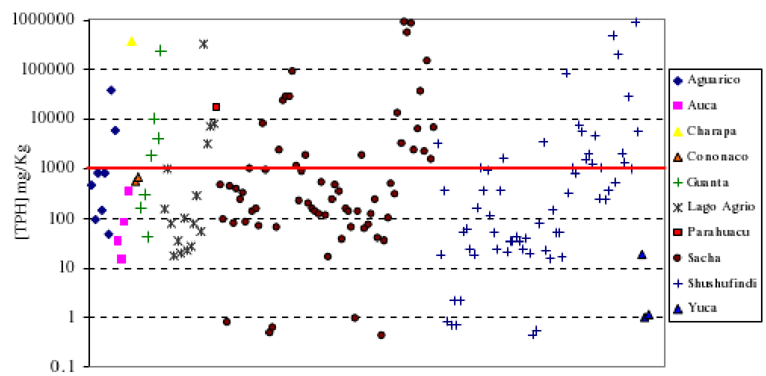


Figure 3. Surface soil TPH results for pit samples, by campo. Note that the data are shown on a logarithmic scale, which changes how the data appear. The red line shows the Ecuador soil TPH standard of 1,000 mg/Kg.



Given the magnitude of TPH contamination, we would expect that toxic oil constituents would also be found in oil field soils. The metals data show that barium, copper, chromium, and zinc concentrations in surface soils are also toxic to terrestrial life. Figures 4 and 5 show surface soil data for barium in non-pit and pit samples. There are two toxicity benchmarks available for barium; one for soil invertebrates (330 mg/Kg) and one for mammals (2,000 mg/Kg). The invertebrate toxicity benchmark was exceeded in 49% of the non-pit and 45% of the pit collected samples. The mammal toxicity benchmark was exceeded in 2% of the non-pit and 3% of the pit collected samples.

Figure 4. Surface soil barium results for non-pit samples, by campo. Note that the data are shown on a logarithmic scale, which changes how the data appear. The red line is the toxicity benchmark for invertebrates (330 mg/Kg) and the blue line is the benchmark for mammals (2,000 mg/Kg).

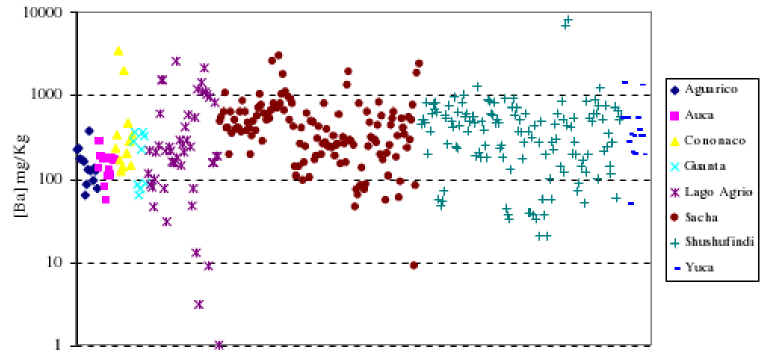
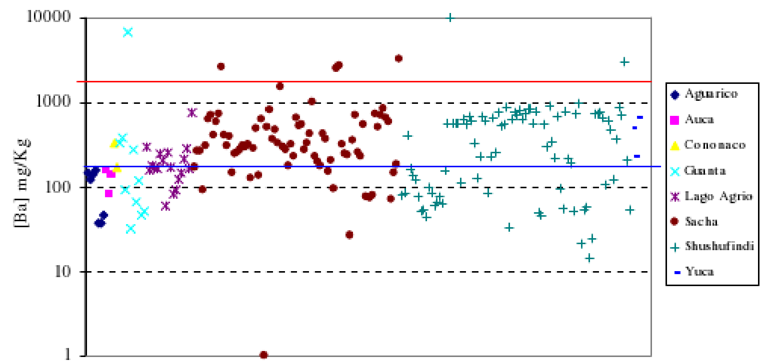


Figure 5. Surface soil barium results for pit samples, by campo. Note that the data are shown on a logarithmic scale, which changes how the data appear. The red line is the toxicity benchmark for invertebrates (330 mg/Kg) and the blue line is the benchmark for mammals (2,000 mg/Kg).



Figures 6 and 7 show surface soil results for copper. There are four toxicity benchmarks available for copper exposure in soil. Birds are most sensitive to copper. The bird benchmark (28 mg/Kg) was exceeded in 66% of the non-pit and 65% of the pit collected samples. Soil invertebrates are least sensitive to copper. The invertebrate benchmark (80 mg/Kg) was exceeded in 6% of the non-pit and 5% of the pit collected samples. These results indicate that terrestrial receptors are at risk from copper contamination.

Figure 6. Surface soil copper results for non-pit samples, by campo. The lines are the soil toxicity benchmarks for soil invertebrates (80 mg/Kg), plants (70 mg/Kg), mammals (49 mg/Kg), and birds (28 mg/Kg), from top to bottom.

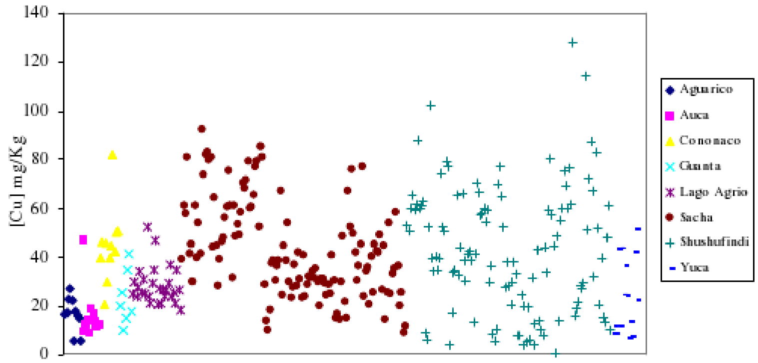
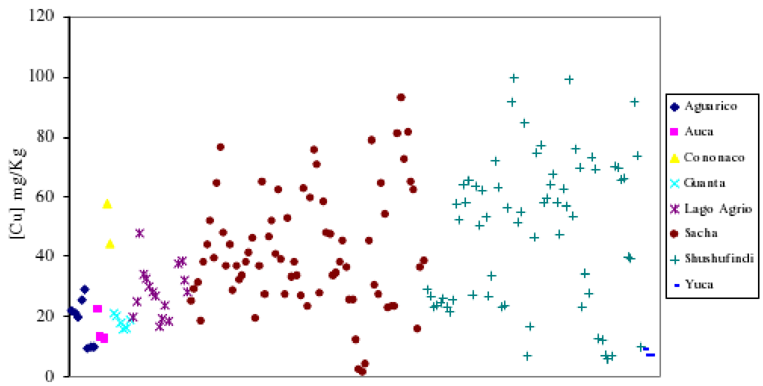


Figure 7. Surface soil copper results for pit samples, by campo. The lines identify the soil toxicity benchmarks for soil invertebrates (80 mg/Kg), plants (70 mg/Kg), mammals (49 mg/Kg), and birds (28 mg/Kg), from top to bottom.



Figures 8 and 9 show surface soil results for chromium. Two toxicity benchmarks are available for chromium; birds (26 mg/Kg) and mammals (34 mg/Kg). The bird toxicity benchmark was exceeded in 25% of the non-pit samples and 36% of the pit samples. The mammal toxicity benchmark was exceeded in 18% of the non-pit and 26% of the pit samples. These results indicate that birds and mammals are at a low level of risk from chromium contamination.

Figure 8. Surface soil chromium results for non-pit samples, by campo. The red line is the toxicity benchmark for birds (26 mg/Kg) and the blue line is the benchmark for mammals (34 mg/Kg).

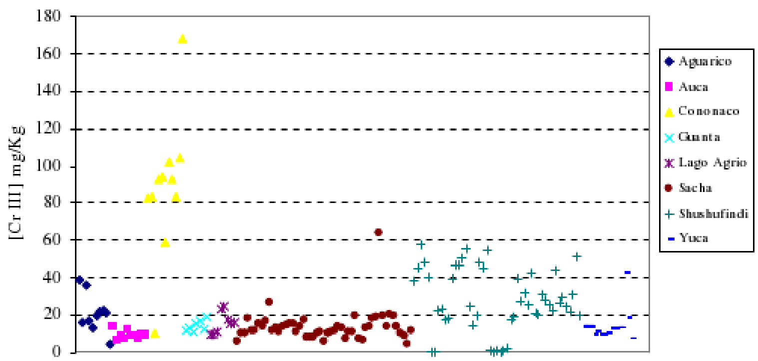
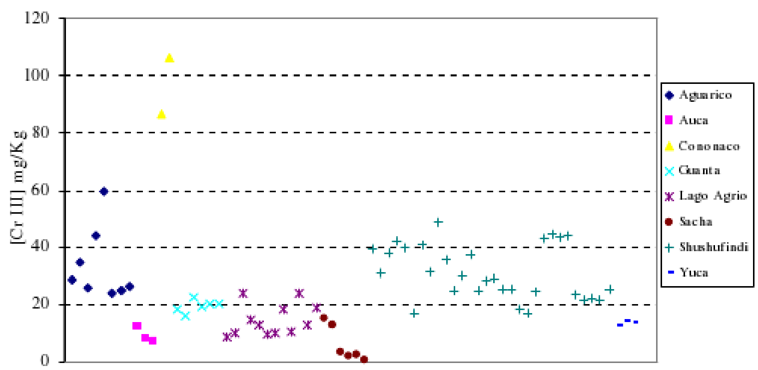


Figure 9. Surface soil chromium results for pit samples, by campo. The red line is the toxicity benchmark for birds (26 mg/Kg) and the blue line is the benchmark for mammals (34 mg/Kg).



Figures 10 and 11 show surface soil results for zinc. There are four toxicity benchmarks available for zinc exposure in soil. Similar to copper, birds are most sensitive to zinc. The bird benchmark (46 mg/Kg) was exceeded in 73% of the non-pit and 70% of the pit collected samples. Plants are least sensitive to zinc. The plants benchmark (160 mg/Kg) was exceeded in 2% of the non-pit and 2% of the pit collected samples. These results indicate that all terrestrial receptors are at risk from zinc contamination.

Figure 10. Surface soil zinc results for non-pit samples, by campo. The lines are the soil toxicity benchmarks for plants (160 mg/Kg), soil invertebrates (120 mg/Kg), mammals (79 mg/Kg), and birds (46 mg/Kg), from top to bottom.

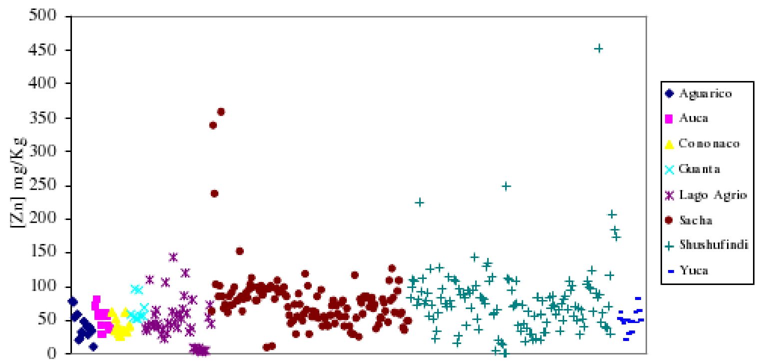
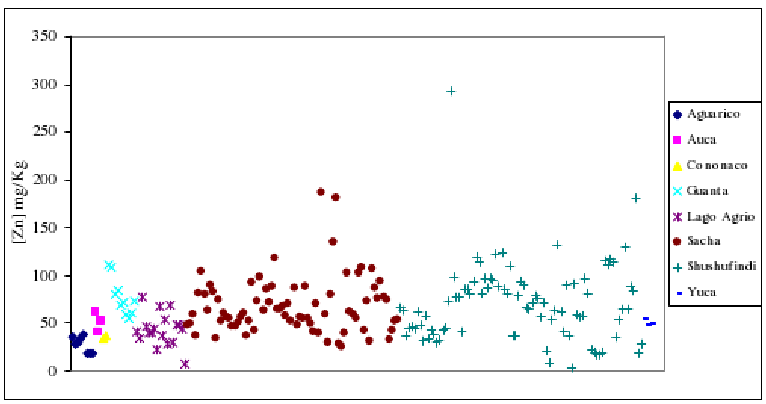


Figure 11. Surface soil zinc results for pit samples, by campo. The lines are the soil toxicity benchmarks for plants (160 mg/Kg), soil invertebrates (120 mg/Kg), mammals (79 mg/Kg), and birds (46 mg/Kg), from top to bottom.



In summary, the data collected in the litigation show that the contamination of surface soils (< 1m deep) in the Concession is high enough to cause toxicity terrestrial life. Of the contaminants studied, TPH (petroleum hydrocarbons) is probably responsible for most of the toxicity. Metals concentrations are also high enough to cause toxicity. Toxic concentrations are present in surface soils from pits and from areas outside of pits. These data show that soil contamination causes toxicity to terrestrial life in the Concession. The toxic effects will vary depending on the concentrations, the organisms, and other factors, and they likely range from sublethal effects, such as reduced growth, to death.

3.7 Field ecology studies in the Concession

In this section we summarize results of two biological investigations conducted in the Concession area. Martinez (2007) studied the diversity of plant communities at different distances from oil wells. Gallo (2007) investigated the diversity of mammals, birds, amphibians, retiles, and aquatic invertebrates in the Concession's oil fields. Fish bioaccumulation was also examined in this study.

Martinez (2007) compared the diversity of Concession plant communities to the diversity of Amazon forests in areas unimpacted by oilfield operations. Their study shows that there are little to no natural species present in the plant communities closest to the well pads. These areas were described as disturbed. Outside of these heavily disturbed areas, fragmented forested areas existed. These fragmented forested areas were described as lacking the diversity to fully sustain a healthy forest ecosystem. The author concludes that the consequences of fragmented forests would result in decreased diversity of flora and fauna and adverse changes in local and global climates.

Gallo (2007) investigated the diversity of Concession fauna through extensive surveys of mammals, birds, amphibians, reptiles, and aquatic invertebrates. The study shows that the diversity of mammals, birds, amphibians, and reptiles is substantially lower than what would naturally occur in similar unimpacted forests. The fauna that are present are those that are highly tolerant of habitat disturbances. For example, species that are adapted to feeding on cultivated crops such as yucca and fruits were common.

Gallo (2007) also investigated the accumulation of contaminants in fish. Fish were collected from the Charapa and Parahuaco rivers near oil wells and pits. Arsenic, cadmium, chromium, copper, lead, mercury, nickel, vanadium, and zinc were all measured in fish tissues. The concentrations of arsenic, cadmium, chromium, mercury, and zinc were routinely higher than consumption limits permissible for humans.

In summary, these two studies show that the flora and fauna in the Concession have low biodiversity and are composed of tolerant species. Furthermore, fish tissue data confirm that biota are exposed to toxic constituents of oil and produced water.

4. SURFACE WATER IMPACTS FROM PRODUCED WATER DISCHARGE

Texaco discharged a total of 60.3 billion liters (15.9 billion gallons) of produced water in the Concession from 1972 through June of 1990 (PetroEcuador files). The impact of the discharged water on surface water is a function of the concentrations of contaminants in the produced water, the amount of produced water discharged at that location, the concentrations of contaminants in surface water under background conditions, and the flow in the receiving stream. Key sources of information available for the case were used to estimate these values and calculate the volume of surface water impacted by the discharge of produced water.

The following assumptions were used to calculate the amount of impacted surface water:

- Discharged produced water mixes instantaneously with the receiving water body
- Flow downstream is in rivers and does not enter wetlands or other areas of very low flow

- Produced water was discharged at the same rate continuously during the period of operation of the station from the date of first production to June 1990

5. VOLUME AND FLOW OF IMPACTED SURFACE WATER

Table 1 is a summary of the background and produced water chloride concentrations, the amount of produced water discharged, and the amount of surface water contaminated by the discharge at each production station. Chloride was used as a measure of surface water impacts because of its high concentration in produced water and its lack of attenuation in natural waters. Compared to metals and many organic compounds, chloride is considered "conservative" because it has a very low tendency to adhere to sediment, to volatilize, or to participate in geochemical reactions such as precipitation (Stumm and Morgan, 1996). The concentration of chloride that is harmful to aquatic biota at a chronic level (long-term exposure) is 230 mg/L (U.S. EPA, 1988). Because produced water was discharged nearly continuously to the environment over a period of many years starting in 1972, chronic exposure of aquatic biota to chloride is an appropriate measure of surface water impacts. Streams in the Concession have naturally low chloride concentrations, and background values vary from 1.3 to 9 mg/L (Table 1).

Table 4: Produced water, upstream background, and impacted surface water information for separation stations in the Concesión

Station	Produced water chloride concentration[a] (mg/L)	Upstream chloride concentration[a] (mg/L)	Produced water discharged until June 1990[g] (L)	Amount of surface water contaminated above standard (L)
Aguarico	47,150	4	2.31E+09	4.73E+11
Atacpi	104,200	1.6	5.72E+08	2.59E+11
Auca Central	8,030	3	3.03E+09	1.06E+11
Auca Sur	21,200	2	2.44E+08	2.25E+10
Cononaco	365	2	7.98E+08	1.27E+09
Culebra	45,600[a1]	3.39[c]	8.96E+07	1.78E+10
Dureno	48,900[a2]	3.39[c]	4.55E+07	9.67E+09
Guanta	48,900[b]	3.39[c]	8.36E+07	1.78E+10
Lago Agrio - Central	418[b]	3.39[c]	2.03E+09	3.69E+09
Lago Agrio Norte	6,380	9.00	7.73E+09	2.14E+11
Parahuacu	6,020[b]	3.39[c]	2.11E+07	5.51E+08
Sacha Central	4,105	3	1.33E+10	2.38E+11
Sacha Norte No.1	2,520	1.7	1.23E+10	1.35E+11
Sacha Norte No.2	1,400	1.3	4.59E+09	2.79E+10
Sacha Sur	1,120	3[d]	3.99E+09	1.94E+10
Shushufindi Central	26,200	2[e]	2.87E+09	3.27E+11
Shushufindi Norte	24,400	2	1.22E+09	1.29E+11
Shushufindi Sur	33,000	3	2.15E+09	3.08E+11
Shushufindi Sur Oeste	37,550	3[f]	2.11E+09	3.44E+11
Yuca	45,600	3.39[c]	5.25E+08	1.04E+11
Yuca Sur	45,600[a1]	3.39[c]	1.99E+08	3.95E+10
Yulebra	45,600[a1]	3.39[c]	1.58E+07	3.12E+09
Totals (liters)			**6.03E+10**	**2.80E+12**

a. Fugro McClelland, 1992, Appendix B (unless otherwise noted).
a1. Used same value as for Yuca, the closest station with a measurement.
a2. Used same value as for Guanta, the closest station with a measurement.
b. HBT AGRA, 1993.
c. Mean upstream chloride concentration from those used from Fugro McClelland, 1992, Appendix B.

d. Used upstream value from Sacha Central (Fugro McClelland, 1992, Appendix B).
e. Used upstream value from Shushufindi Norte (Fugro McClelland, 1992, Appendix B).
f. Used upstream value from Shushufindi Sur (Fugro McClelland, 1992, Appendix B).
g. PetroEcuador files.

The amount of surface water contaminated above water quality standards at a given separation station was calculated using the chloride concentration in and amount of produced water and the value of the chloride standard (230 mg/L). The amount of water contaminated above the Standard during the time that Texaco operated the Concession (1972 to June 1990) varied from 551 million liters at the Parahuacu Station to 474 billion liters at the Aguarico Station. The total amount of surface water contaminated above the water quality standards for all the stations throughout period was 28 billion liters. The annual average flow of surface water contaminated by discharges of production water from 1972 to 1990 was 5,939 liters per second.

The amount of water contaminated above background conditions during Texaco's operations varied from 37.4 billion liters at the Parahuacu Station to 37.7 trillion liters at Shushufindi Central Station.

6. CONCLUSIONS

Oil exploration and production activities in the Concession have released toxic chemicals into the environment. This annex evaluates whether the resulting contaminant concentrations are low enough to be safe, or high enough to cause toxicity to ecological life. The analysis presented here shows that contaminant concentrations in surface waters and soils are sufficiently high to toxicity in exposed biota. Of particular concern are hydrocarbons and inorganic constituents originating from crude oil and produced water.

Streams and rivers in the vicinity and downgradient of oil wells, pools, and production stations are or have been toxic to aquatic life. In these environments, aquatic biota are exposed to water soluble hydrocarbons such as BTEX and inorganic contaminants such as chloride, cadmium, chromium, copper, nickel, and lead. The concentrations of these contaminants measured in streams and rivers in the Concession make these waters unsuitable for aquatic biota.

Surface soils in areas of wells and stations are also contaminated from toxic constituents of oil, produced water, and various oil extraction and production activities. Site soil data indicate that concentrations of TPH, barium, copper, chromium, and zinc are high enough to cause toxicity to plants, invertebrates, birds, amphibians, and mammals. Surface soils both in pits and outside of pits are toxic.

Overall, the available data show that the ecology of the Concession has suffered from the toxic effects of contamination. The data show that the effects to terrestrial life are greatest in the areas of oil wells and stations, and that the effects to aquatic life were greatest in rivers downstream of stations.

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APPENDIX N: CABRERA REPORT APPENDIX N

ANNEX N: SOIL REMEDIATION COSTS

Por: Equipo Técnico del Ing. Richard Cabrera
como parte del
EXAMEN PERICIAL

24 de Marzo del 2008

1. AMOUNT OF CONTAMINATED SOIL REQUIRING REMEDIATION

The permissible limit for petroleum contamination in soils of sensitive ecosystems is 1,000 ppm TPH. Although soils in the Napo Concession are contaminated with other chemicals besides crude oil, such as metals, TPH is used as the indicator for soil cleanup because most of the soil contamination comes from crude oil, and because most of the available data in the Concession are for TPH. Some assumptions are required to develop an estimate of the amount of soil that requires remediation. This is because the sampling that has been done has not defined the exact spatial extent and depth of all contaminated soils within the Concession. However, as is discussed in Annex G, the information from the sites that have been sampled is sufficient to develop an overall estimate for the entire Concession.

1.1. Surface area of soils that require remediation

Table 1 lists the estimated surface area of soils that require remediation at stations and well sites. There are 89 pits at stations that cover 77,500 m^2 in area. Because the stations processed such large amounts of oil and produced water in the pits, it is safe to assume that all of these pits require remediation.

Table 1: Surface area of Concession soils requiring remediation (>1,000 ppm TPH)

Soil surface area	Wells	Stations	Total
Total surface area of pits	691,000 m^2	77,500 m^2	769,000 m^2
Surface area of pits requiring remediation	553,000 m^2 (80% of pit soils)	77,500 m^2 (100% of pit soils)	631,000 m^2
Surface area of soils outside of pits that require remediation (50% of pit soils)			316,000 m^2
Total surface area of soils requiring remediation			**947,000 m^2**

There are about 828 pits at oil well sites that cover 691,000 m^2 in area. Based on the data analysis presented in the main report, approximately 80% of these pits contain soils with TPH concentrations greater than 1,000 ppm. Therefore, we estimate that 80% of the pits at wells require remediation, or 662 pits. If we also assume that the areas of the pits that require remediation are representative of all of the pits, then the total surface area of well pits that require remediation is 553,000 m^2.

In addition to the pits, there are also other areas at the stations, wells, and other areas that are contaminated with crude oil. Oil seeped through the sides of the pits into the surrounding soils. At some pits, oil has overflowed the pits and contaminated the surrounding soils. Some pits also had pipes constructed in their sides to drain the oil if the level in the pit became too high. There also have been many spills of crude oil at pits and stations. For example, there were at least hundreds of spills totaling thousands of barrels of oil reported at wells during the years that Texpet operated the Concession. Some of these spills were reported to be cleaned up, but not all were. There were also many other oil spills throughout the Concession from pipelines and other operations, in addition to the spills at wells.

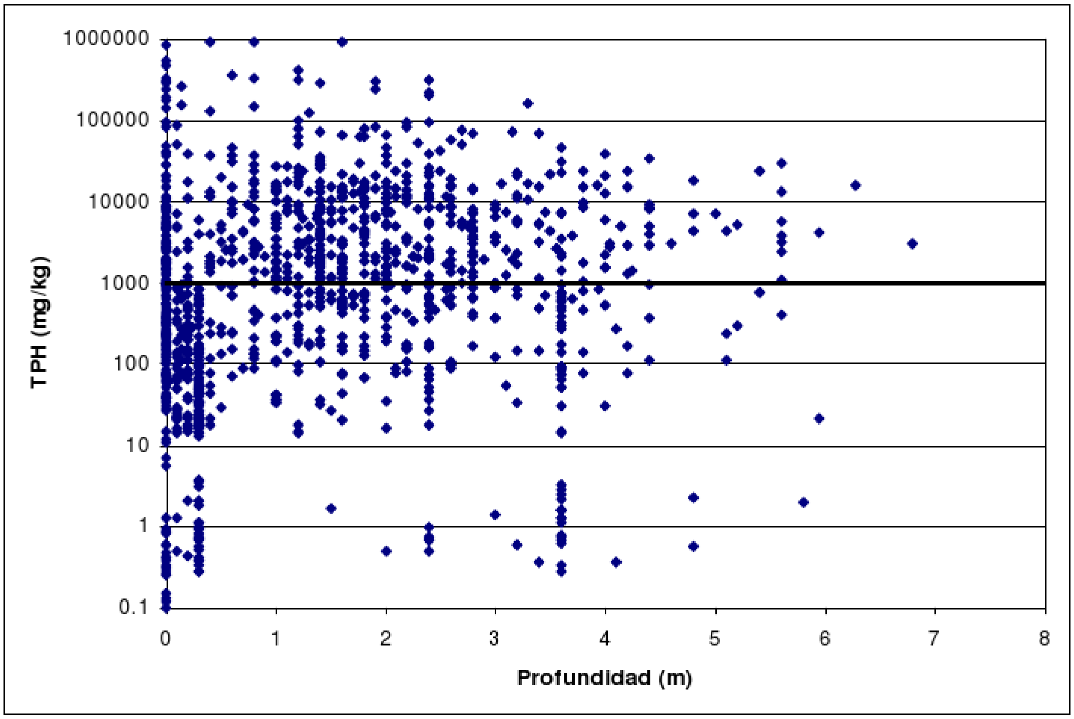
The data collected during the Judicial Inspections confirm that there is widespread contamination at the wells and stations outside of the pits. The main report describes that many of the soil samples collected from outside of pits are contaminated with TPH at concentrations much higher than 1,000 ppm. In most cases, the exact source of this contamination outside of pits could not be identified, other than they were spills. However, the data are not sufficient to determine exactly how much soil outside of pits is contaminated with oil in the Concession. To do so would take many, many years and many thousands of soil samples. Instead, an estimate can be made based on the soil data from the Judicial Inspection and the history of oil spills in the Concession. The area of soils outside of pits that requires remediation is estimated as being about 50% of the area of the pits that require remediation. This estimate comes to 316,000 m^2. The total area of soil requiring remediation (in pits and outside of pits) is 947,000 m^2.

1.2. Soil volume that requires remediation

To estimate the soil volume that requires remediation, it is necessary to have an estimate of how deep the contamination goes. Many of the soil samples collected as part of the litigation were collected from underground, and therefore we have data on how deep the soil contamination is. The soil samples that were collected underground were collected using coring devices that collect a long soil sample in a hollow tube. Soil from the different depths are then removed and sent to the laboratory for analysis. Figure 1 shows TPH contamination in all of the soil samples collected during the Judicial Inspections by depth.

The figure shows that much of the soil at all depths has TPH greater than 1,000 ppm. The figure also shows that contamination above 1,000 ppm TPH extends to quite deep below the surface. Most of the samples from the 5 to 6 m depth below the surface have TPH concentrations greater than 1,000 ppm. Many of the contaminated samples shown in the figure are in fact from the deepest segment of soil retrieved from a core. This means that the actual depth of contamination extends deeper than what is shown in the figure, since the deepest sample collected often contained greater than 1,000 ppm TPH. The figure shows a certain tendency of TPH concentrations to decrease below 1000 ppm TPH with depth. Its certain that contamination occurs in soils at all depths, although it seems to have tendency to decrease with greater depth.

Figure 1: TPH concentrations in all soil samples, by depth. The data are plotted on a logarithmic scale, which means that the concentration at each horizontal line is ten times higher than the line below it.



The data in the figure show that the remediation will have to go quite deep down to get all of the contaminated soil above 1,000 ppm TPH. The actual depth will vary from site to site, and probably from pit to pit at each site. Based on the figures, it is safe to estimate that pit remediation will have to go down about 4 m, on average, to get all of the contaminated soil. Therefore, a depth of 4 m (on average) is used to estimate the total volume of soil that requires remediation.

Table 2 shows the calculation of the total volume of soil that requires remediation.

Table 2: Total soil volume requiring remediation

Total surface area of soils requiring remediation	Average depth of remediation	Total soil volume for remediation
947,000 m^2	4 m	3,788,000 m^3

2. REMEDIATION COST ESTIMATE

2.1. Applicable technologies

There are many remediation technologies available for cleaning up soils contaminated with crude oil. The selected clean-up technology should fulfill the remediation objectives to prevent all migration or movement of toxic substances outside the contaminated areas, and to reduce TPH values to less than 1000 ppm. Proyecto Eliminación de Piscinas Contaminadas en el Distrito Amazónico (PEPDA) is currently engaged in clean-up of contaminated soils in and around some of the waste pits in the Concession. They are primarily using soil washing as the remediation technology, at a minimum cost of approximately $60 per cubic meter ($m^3$) of treated soil. TexPet also conducted remediation activities in the mid-1990s, and soil washing was an important element of their work as well. Annex PITS describes how there is still TPH at concentrations well above 1,000 ppm at the pits where TexPet conducted their cleanup activities, demonstrating that the methods they used are not adequate to reach a cleanup target level of 1,000 ppm TPH.

Soil washing relies on the fact that light hydrocarbons will float on top of water, and therefore requires that the pits are filled with water for application of this technology. If the pits are not naturally filled with water, then they are pumped full of water prior to soil washing application. Remediation technicians manually insert an air hose into the water-filled pits to agitate the water, thereby promoting free-phase petroleum to bubble to the surface, where it can be physically skimmed off the water. In some cases, detergents are added to the water/soil to aid in the extraction of hydrocarbons. This remediation technology is effective at retrieving some of the free-phase petroleum contamination from the soil. Figure 2 illustrates free-phase petroleum contamination that is recoverable using soil washing as a remediation technology.

Figure 2: A photo of the petroleum contamination recovered in a waste pit using soil washing.

While removing some of the free-phase petroleum contamination from the waste soils contributes to the overall clean-up, it is ineffective at removing all of the free-phase petroleum contamination as well as hydrocarbon contamination adsorbed to the soil. This leaves contaminated soils in place. As illustrated in Figure 3, the stained soils in the waste pit show evidence of hydrocarbon contamination not recovered using soil washing. Data from the Judicial Inspections demonstrate that pits remediated by TexPet in the 1990s using technology such as soil washing contain TPH concentrations at concentrations well in excess of 1000 ppm TPH, as described in Annex H Therefore, we conclude that soil washing alone is not adequate for remediation of the contaminated soils to achieve a level of less than 1,000 ppm TPH.

Figure 3: A PEPDA soil washing operation at a contaminated pit.

There are other technologies available for the treatment of soils, such as physical removal, chemical fixation, in-situ or ex-situ chemical treatment or decontamination, in-situ or ex-situ bioremediation, incineration or thermal destruction, and other similar processes. The cleanup technology that is selected must meet the cleanup objectives of preventing any further migration or movement of contaminants away from the contaminated areas, and the reduction of TPH concentrations to less than 1,000 ppm. The relative merits of each technology are discussed below.

All cleanup technologies are aimed at controlling, reducing, or eliminating the exposure of toxic and other chemicals to either human receptors or sensitive ecosystems. In general, the selection of the preferred technology must consider the following criteria:

- Regulatory compliance, or other project goals and objectives
- Engineering feasibility in terms of implementation
- Track record and applicability of technology
- Economics associated with implementation
- Logistical considerations
- Social and infrastructure considerations

Aesthetic restoration only

Aesthetic restoration would be applicable to those sites at which contamination is either very low impact in terms of its nature or extent, or is not likely to significantly impact either human receptors or sensitive ecosystems. In such cases, light construction equipment such as backhoes and graders could be used to move waste material and add clean soil fill. Re-vegetation may be necessary to minimize the potential for erosion. However, aesthetic restoration cannot prevent the continued release of contaminants from the contaminated pits and soils, and it will not achieve any significant progress toward reducing TPH concentrations to less than 1,000 ppm.

Isolation of waste material

Isolating waste material refers to actions that prevent further migration or spread of the contamination, but do not actively reduce the contamination that is present. Isolation could include such actions as installing slurry walls around the pit to isolate the waste material from adjacent clean soils, thereby minimizing the potential for further lateral contamination. To be effective, slurry walls must be sufficiently deep. Slurry walls can isolate contaminated groundwater from uncontaminated groundwater, but this practice is highly site specific. Capping and covering waste areas can help isolate the waste material from rainfall events, run-off and run-on, and nearby residents and wildlife, thereby minimizing exposure. However, if the pit is not geotechnically stable, the waste material must first be stabilized in order for capping and covering to be effective. Isolation restoration may assist in preventing the continued release of contaminants from the pits into surface water and groundwater resulting from rainfall events, continued leaching into the soil, etc. However, it does nothing for removing the long-term threat or reducing the contamination that is in place. For this reason, isolation restoration was not considered in this evaluation.

Physical stabilization and chemical fixation

Remediation through the use of physical stabilization (sometimes referred to as solidification) could be used at many of the pit sites. Solidification involves the addition of chemical reagents that physically solidify the material, thereby minimizing movement and creating stability. Solidification typically does not eliminate the leaching of waste materials over time, unless an impermeable cap is used to isolate the stabilized material from rainfall events, run-on, etc. On the other hand, chemical fixation creates a more impermeable monolith that minimizes leaching, although typically at a greater cost. Physical stabilization and/or chemical fixation, however, does not remove contaminated soil and therefore cannot guarantee the prevention of the continued release of contaminants, nor does it reduce the contaminant concentrations appreciably. For these reasons, physical stabilization and chemical fixation were not considered in this evaluation.

In-situ and ex-situ chemical treatment

Remediation of waste pit soils using chemical treatment either in-situ (in place) or ex-situ (after removing the contaminated soils from the pits) may be viable at many sites. This technology involves the use of oxidants or other reagents to treat petroleum hydrocarbons. Other reagents are available to treat toxic metals and salinity, although no single reagent can treat all three classifications of wastes. In-situ treatment involves the injection or mixing of reagents directly into the waste material. Ex-situ treatment involves the removal of the waste material, treatment, and subsequent replacement of the treated waste material back into the original excavation. Based on an assessment of the pits, in-situ or ex-situ chemical treatment is not a viable technology. The relative cost of in-situ or ex-situ chemical treatment is high compared to other technologies. However, such technology can be used in conjunction with bioremediation for a more effective overall treatment program. For example, oxidants can establish better aerobic conditions for bioremediation.

In-situ or ex-situ bioremediation

In-situ or ex-situ bioremediation could be used to restore sites contaminated with petroleum hydrocarbons, assuming that other contaminants such as toxic metals or salinity would not limit the microbial degradation of waste material. Bioaugmentation would involve adding microbes plus nutrients, whereas biostimulation would involve adding only nutrients to a contaminated site that already has an indigenous microbial population. Bioremediation could be implemented in the in-situ mode at sites with either shallow contamination or minimal hydrocarbon loading. For sites with either deep or highly concentrated hydrocarbon contamination, such as those considered in this evaluation, the ex-situ mode may be preferred. Ex-situ treatment involves the removal of the waste material, biotreatment, and subsequent replacement of the treated waste material back into the original excavation. However, bioremediation takes years to accomplish, and requires active monitoring and maintenance. Based on an assessment of the pits, bioremediation is a viable technology, and ex-situ bioremediation is the preferred application. The relative cost of bioremediation is low compared to other technologies.

Incineration or thermal treatment

Remediation through the use of either incineration or thermal treatment could potentially apply to all sites that are primarily impacted with petroleum hydrocarbons. The presence of salinity, toxic metals, and other substances can limit the technology or increase the relative cost. This technology involves excavating waste material using small to large excavation machinery, loading the waste material onto trucks, and transporting the waste material to a commercial incineration or thermal treatment facility. Alternatively, mobile units could be used to travel from site to site, treating the waste. The excavated area is then backfilled with clean soil fill material, revegetated, and restored. This is common practice in countries such as the United States where incineration and thermal treatment portable units or fixed facilities are readily available. Based on an assessment of the pits, incineration and thermal treatment is not a viable technology. The relative cost of incineration and thermal treatment is generally high compared to other technologies.

In summary, isolation and/or institutional and aesthetic remediation does not remove contaminated soils, and therefore does not achieve the stated clean-up goals of remediating contaminated soils to concentrations less than 1000 ppm TPH. Therefore, a technology that achieves active reduction of contaminant concentrations must be used. Based on an assessment of the waste pits and consideration of the relative effectiveness and cost of remediation technologies, physical removal of the contaminated soil material, in combination with additional treatment such as bioremediation is the preferred remediation technology to meet the cleanup objectives.

2.2. Remediation unit costs

This evaluation estimates remediation costs by using data from analogous remediation projects. In their Judicial Inspection reports, ChevronTexaco relied on data available through the U.S. Federal Remediation Technologies Roundtable (FRTR) to derive estimated remediation costs. This evaluation relies on this same data, and considers remediation projects that used a combination of soil removal and additional treatment to achieve clean-up goals (Table 3). All of the project sites have contamination sources from petroleum products, and all of the selected projects used physical removal and additional treatment as a remediation technology to clean-up hydrocarbon contamination in soils.

Table 3: Costs for remediation projects similar to the soil cleanup needed in the Concession

Project Name	Year	Contaminant	Technology	Unit Cost (2007 $/m³)
Payment production at the site of the Dubose Oil Products Co, Superfund Site, Cantonment, Florida.	1994	BTEX, TPH	Ex situ bioremediation	1078
Soil treatment (soil pile) in UST in Fort Greely, Alaska	1997	BTEX	Ex situ bioremediation	98
Soil treatment in underground dumps of storage (UST) in the Air Force base (AFB) of Lowry, Denver, Colorado	1993	BTEX, TPH	Ex situ bioremediation	55
Soil treatment conducted by Bonneville Power Administration Ross Complex agency, operative Unit A, zone of wood post storage, Vancouver, Washington	1996	HPAH	Ex situ bioremediation	812
Soil treatment at the Brown Wood Preserving Superfund Site, Live Oak, Florida	1990	PAH	Ex situ bioremediation	162
Soil treatment at the Scott Lumber Company Superfund Site, Alton, Missouri	1991	PAH	Ex situ bioremediation	757
Bioremediation of the mud phase at the French Limited Superfund Site, Crosby, Texas	1993	PAH	Ex situ bioremediation	460

The cost to remediate contaminated soils for these analogous projects range from $55 to $1078/m^3 of contaminated soil, with an average cost of $489 USD/m^3 of soil.

2.3. Unit cost estimate limitations

The unit cost estimate presented above relies on some assumptions that can influence the accuracy of the actual cost once implemented. Some assumptions may lead to an overestimate of the true cost, and some may lead to an underestimate. For example, the unit cost estimate could be too high because it is based on projects in United States, where labor rates are higher than in Ecuador. Estimation of costs also could be high because they specifically do not consider the potential savings in the costs realized by clean-up at a large scale. On the other hand, the ongoing PEPDA cleanup in the Concession is reported to cost about $60/m^3, and it is a much less aggressive and much less expensive cleanup than what is proposed here. The cost estimate could also be too high because it does not specifically consider potential cost-savings of doing the cleanup on such a large scale. On the other hand, the cost estimate could be too low because certain remediation costs could compound as a result of the large scale of treatment that is required. This would include the costs of having to build and maintain roads, housing, healthcare, provisions for workers, other infrastructure, etc. The cost could also be too low since the cost estimate does not include the costs of additional items such as post-cleanup monitoring. A thorough quantitative evaluation of these, and other, considerations would be required to further limit uncertainty in the cost estimates. Regardless, the cost estimate provided here is reliable and can be used to estimate what is required to conduct the required remediation in the Concession.

3. TOTAL REMEDIATION COSTS

The total estimated cost to remediate the volume of contaminated soils throughout the site is calculated by multiplying the volume of soil requiring remediation (from Section 1.2) times the per unit remediation cost (Table 4). The total estimated remediation cost for contaminated soils is $1,697,000,000.

Table 4: Total estimated soil remediation cost

Total soil volume for remediation	Average cost to remediate contaminated soils	Total cost to remediate contaminated soils
3,788,000 m^3	$489 USD/$m^3$	$1,852,000,000 USD

APPENDIX O: COST ASSESSMENT FOR PHYTOREMEDIATION

SOIL TECHNOLOGY:	Phytoremediation			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
Contaminated Media	Soil	Soil	Soil	Soil
Fencing	None	None	None	None
Site Distance	250	250	250	250
Safety Level	D	D	D	D
Depth to Contamination (ft)	0.1	0.1	0.1	0.1
Area of Contamination (SF)	135,000	135,000	2,700,000	2,700,000
Type of Contaminant	Metals	Metals	Metals	Metals
Irrigation	Existing service Connection	Existing service Connection	Existing service Connection	Existing service Connection
Contaminated Volume (Cubic Feet)	13,500	13,500	270,000	270,000
Contaminated Volume (Cubic Yards)	500	500	10,000	10,000
Natural Attenuation (Sampling)				
Crew Size	2 field technicians	2 field technicians	2 field technicians	2 field technicians
Site Distance (miles)	250	250	250	250
Analytical Water	None	None	None	None
Analytical Soil	Surface Soil	Surface Soil	Surface Soil	Surface Soil
Analytical Template	Metals	Metals	Metals	Metals
Include QA/QC Samples	Yes	Yes	Yes	Yes
Include Data Analysis/Reporting	Yes	Yes	Yes	Yes
Surface Soil Monitoring- # of events	1	1	1	1
Surface Soil Monitoring- # of samples	6	6	124	124
Surface Soil Monitoring- # of years	5	20	5	20
Subsurface Soil Monitoring- Avg. Depth (ft)	N/A	N/A	N/A	N/A
Subsurface Soil Monitoring- # of events	N/A	N/A	N/A	N/A
Subsurface Soil Monitoring- # of samples	N/A	N/A	N/A	N/A
Subsurface Soil Monitoring- # of years	N/A	N/A	N/A	N/A
Phytoremediation Marked-up Costs	$26,181	$26,181	$272,226	$272,226
Natural Attenuation (Sampling) Costs	$176,367	$770,691	$770,720	$3,079,798
Additional Costs:				
O&M	$29,590	$83,255	$39,191	$297,578
Years of O&M	5.0	20.0	5.0	20.0
Remedial Design	$7,344	$7,554	$39,709	$41,888
TOTAL MARKED-UP COSTS	$239,482	$887,681	$1,121,846	$3,691,490
COST PER SQUARE FOOT	**$2**	**$7**	**$0.42**	**$1**
COST PER CUBIC FOOT	**$18**	**$66**	**$4**	**$14**
COST PER CUBIC METER	**$626**	**$2,322**	**$147**	**$483**
COST PER CUBIC YARD	**$479**	**$1,775**	**$112**	**$369**

APPENDIX P: COST ASSESSMENT FOR SOIL VAPOR EXTRACTION

SOIL TECHNOLOGY:	Soil Vapor Extraction			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
Remedial Action:	**Easy**	**Difficult**	**Easy**	**Difficult**
Media/Waste Type	Soil	Soil	Soil	Soil
Contaminant	SVOCs	SVOCs	SVOCs	SVOCs
Approach	In Situ	In Situ	In Situ	In Situ
System Definition:				
Installation Type	Vertical well	Vertical well	Vertical well	Vertical well
Soil Type	Sand Silt/Sand Clay	Silt/Silty-Clay Mixture	Sand Silt/Sand Clay	Silt/Silty-Clay Mixture
Safety Level	D	D	D	D
Surface Area of Contamination (SF)	450	450	2,700	2,700
Depth to Base of Contamination (FT)	5	5	5	5
Drilling:				
Average Well Depth (FT)	5	5	5	5
Formation Type	Unconsolidated	Unconsolidated	Unconsolidated	Unconsolidated
Safety Level	D	D	D	D
Well Diameter (IN)	2	2	2	2
Drilling Method	Hollow Stem	Hollow Stem	Hollow Stem	Hollow Stem
Well Construction Material	PVC sch. 40	PVC sch. 40	PVC sch. 40	PVC sch. 40
Avg. # of Soil Samples per Well	1	1	1	1
Soil Analytical Template	System soils-SVOC	System soils-SVOC	System soils-SVOC	System soils-SVOC
Vertical Wells:				
Extraction Well Spacing (FT)	35	22	35	22
Number of Vapor Extraction Wells	1	2	3	8
Avg. Vapor Flow Rate per Well (CFM)	15	6	15	6
Total Vapor Flow Rate (CFM)	15	12	45	48
O&M:				
Duration (YR)	2	2	2	2
Treatment Train Systems Maintenance Level	Moderate	Moderate	Moderate	Moderate
Sampling Frequency	Monthly	Monthly	Monthly	Monthly
Additional Costs:				
O&M	$51,689	$62,094	$78,404	$180,087
Remedial Design (10% or 10K)	$10,000	$10,000	$10,000	$17,125
SVE Marked-up Costs	$18,606	$21,442	$64,585	$171,253
TOTAL MARKED-UP COSTS	$80,295	$93,536	$152,989	$368,465
COST PER CUBIC FOOT	**$36**	**$42**	**$11**	**$27**
COST PER CUBIC METER	**$1,275**	**$1,485**	**$405**	**$975**
COST PER CUBIC YARD	**$944**	**$1,100**	**$300**	**$722**

APPENDIX Q: COPING WITH TECHNOLOGICAL DISASTER

Journal of Traumatic Stress, Vol. 13, No. 1, 2000

Coping with Technological Disaster: An Application of the Conservation of Resources Model to the *Exxon Valdez* Oil Spill

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One hundred twenty-five commercial fishers in Cordova, Alaska, completed a mailed survey regarding current mental health functioning 6 years after the Exxon Valdez *oil spill. Economic and social impacts of the oil spill and coping and psychological functioning (modified Coping Strategies Scales, Symptom Checklist 90-R) were measured. Multiple regression was used to test the utility of the Conservation of Resources stress model for explaining observed psychological symptoms. Current symptoms of depression, anxiety, and Posttraumatic Stress Disorder were associated with conditions resource loss and avoidant coping strategies. The Conservation of Resources model provided a framework for explaining psychological impacts of the oil spill. Future research is needed to identify factors related to recovery.*

KEY WORDS: technological disasters; *Exxon Valdes* oil spill; Conservation of Resources model.

Research on the effects of disasters has consistently found significant impacts on mental health functioning, with depression, anxiety, and Posttraumatic Stress Disorder (PTSD) emerging as the most common psychological sequelae (for a review, see Green & Lindy, 1994). In addition, somatic complaints, relationship problems, and increased visits to mental health or medical facilities have also been reported. Green and Lindy (1994) contend that postdisaster mental health effects are most common within 2 years following a disaster. However, longer-term effects may also occur, with some individuals remaining symptomatic for as long as 14 years (Green et al., 1990; Green, 1996). Much of this research has focused

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on natural disasters, where mental health consequences generally dissipate within 2 years (Drabek, 1986; Green & Lindy, 1994). In contrast, technological disasters have been found to result in chronic impacts both to the individual and to the community in which the disaster has occurred (Baum, 1987; Baum & Fleming, 1993; Erikson, 1994; Farberow, 1985; Fleming & Baum, 1985; Kroll-Smith & Couch, 1993b).

The long-term, corrosive impacts of technological disasters have been documented in a number of studies. For example, Baum and Fleming's (1993) research on Three Mile Island identified increased somatic distress, anxiety, and depression among individuals for as long as 6 years following the accident. In addition, they found that biochemical changes, such as prolonged elevations in blood pressure and impaired immune system functioning, accompanied this pattern of chronic stress. Chronic mental health impacts have also been observed at toxic waste sites (Couch & Kroll-Smith, 1985; Kroll-Smith & Couch, 1993a) and for other instances of human-caused toxic contamination (Edelstein, 1988; Brown & Mikkelsen, 1989; Erikson, 1994).

Chronic impacts may result from factors immediately related to the causal agent of the disaster, as well as changes in the community observed at some later time. Given the human origins of technological disasters, relief and compensation strategies are often negotiated through litigation, thereby extending the time period for rehabilitation and recovery of victims (Picou & Rosebrook, 1993). Technological disasters, in particular, have been found to lead to a pattern of social deterioration referred to as the "corrosive community" (Freudenburg, 1997; Freudenburg & Jones, 1991; Kaniasty & Norris, 1993; Kroll-Smith & Couch, 1993a). Freudenburg and Jones (1991) suggest that this corrosive context includes community members struggling over where to place blame, authorities being evasive and unresponsive, and victims becoming suspicious and cynical. The present study examines the long-term consequences of a technological disaster (the *Exxon Valdez* oil spill) in which litigation has been protracted and the community has appeared to become corrosive. Effects are measured for a high-risk group (commercial fishers) and a theoretical model for understanding variations in functioning within this group is evaluated.

Conservation of Resources Model. Hobfoll's Conservation of Resources (COR) model of stress-response provides a theoretical framework for understanding the effects of both natural and technological disasters (1988, 1989). Hobfoll postulates that people are motivated to obtain, retain, and protect that which they value. Resources are defined as anything that people value or that enable them to obtain or protect that which they value. Resources can include possessions, personal characteristics, social systems (family and other interpersonal relationships), and financial resources and the ability to attain and retain the above resources. Hobfoll categorized resources into (1) objects (e.g., car, house, boat), (2) personal characteristics (e.g., self-esteem, self-concept, sense of mastery), (3) conditions (e.g., marriage, interpersonal relations), and (4) energies (e.g., credit, money, owed favors). Hobfoll suggests that any event which results in actual or perceived loss of resources, or a lack of expected resource gain, will produce psychological stress. Whereas at times disasters result in substantial loss of possessions and economic resources, disasters may also generate resource loss through disruption of social systems, personal characteristics, and the ability to attain and retain resources (Freudenburg & Jones, 1991; Picou & Gill, 1996).

In recent years, a number of researchers have examined the utility of the COR model for predicting distress related to natural disasters. Freedy, Shaw, Jarrell, and Masters (1992) evaluated the effects of resource loss on psychological functioning following Hurricane Hugo in Charleston, South Carolina. While demographic factors (gender, marital status, and household income) and coping behaviors made significant contributions to levels of distress, they found that resource loss was the strongest predictor of psychological distress 8 weeks after the Hurricane.

The COR model was also tested among college students in Charleston 4 weeks following Hurricane Hugo (Kaiser, Sattler, Bellack, & Dersin, 1996). Kaiser and associates found that resource loss and depression accounted for the greatest portion of variance in psychological distress. Similarly, Freedy, Saladin, Kilpatrick, Resnick, and Saunders (1994) found that the COR model was also effective for predicting distress following the Sierra Madre earthquake (1991) in Los Angeles County. Again, resource loss was a significant predictor of psychological distress, even when controlling for demographic variables and trauma history.

These studies focused on applications of the COR model to short-term impacts of natural disasters. The present research expands this area of inquiry to include an evaluation of the COR model for explaining the chronic (6 years) impacts of a major technological disaster.

The Exxon Valdez *Oil Spill*. On March 24, 1989, the supertanker *Exxon Valdez* ran aground on Bligh Reef in Prince William Sound, Alaska. Approximately 42 million liters of oil was released into valuable commercial fishing grounds. While clearly a human caused technological disaster, the primary impact was perceived by many to be ecological, with few direct human consequences (Lord, 1997). This was the largest oil spill in North American history and ecological impacts continued to be identified 10 years after the event (Spies, Rice, Wolfe, & Wright, 1996; *Exxon Valdez* Oil Spill Trustee Council, 1999).

Commercial fishers in Prince William Sound experienced significant economic impacts in the two years immediately following the oil spill. Losses in revenue for fishers totaled over 155 million dollars during this time period (Cohen, 1995, 1997). Long-term economic losses continued from 1993 to 1997, with a total collapse of the commercial herring fishery for 5 years and a significant downturn in the pink salmon fishery (Schneider, 1993; Spies et al., 1996). These economic damages have not been mitigated through litigation, as legal appeals to a $5 billion jury award to commercial fishers continue to be reviewed by the courts 10 years following the spill.

Commercial fishing and resource harvests associated with subsistence culture are important social activities in Alaskan communities (Wolfe, 1983). These activities serve as sources of economic gain and are a part of how individuals define themselves and their quality of life. While the oil spill did not result in immediate loss of human life or damage to material possessions, it did result in economic damages and losses, as well as disruption of subsistence behavior in local communities (Cohen, 1997; Fall & Field, 1996). The importance of this loss for producing significant mental health effects was documented in a number of initial studies of the *Exxon Valdez* disaster.

One year after the spill, Palinkas, Russell, Downs, and Peterson (1992) studied Alaskan residents of 11 communities in the region directly exposed to the spill, with 2 communities in areas not directly exposed to the spill. Respondents completed a questionnaire which asked about exposure experiences, with exposure defined as prior use of coastal areas affected, work in cleanup activities, contact with oil spill-related activities, or effects of the spill on areas used for commercial and subsistence hunting, fishing, or gathering. Greater exposure to the spill was associated with higher levels of depression and a reported decline in social relationships.

Using the same sample, Palinkas, Peterson, Russell, and Downs (1993) examined rates of mental disorder and compared the mental health effects for individuals with high, low, and no exposure to the oil spill. One year following the spill, they found a prevalence rate of 20% for generalized anxiety disorder and 9% for PTSD, with 16.6% scoring in the clinical range on a depression scale. Greater exposure to the spill was associated with significantly higher rates of Generalized Anxiety Disorder and PTSD and high levels of depressive symptoms.

From 1989 to 1997, Picou and associates conducted a longitudinal study of an Alaskan community, Cordova, which was affected economically by the spill. In initial studies of spill consequences (Picou, Gill, Dyer, & Curry, 1992; Picou & Gill, 1996; Picou, Gill, & Cohen, 1997), effects of the spill were compared for residents of Cordova and residents of two control communities, Valdez and Petersburg, Alaska. Picou et al. (1992) identified higher levels of intrusive stress and avoidance behavior among members of the affected community compared to residents of Petersburg.

The purpose of the present study was to investigate the chronic effects of the oil spill by measuring symptom levels for anxiety, depression, and PTSD and social disruption among Alaskan fishers 6 years after the disaster. Specifically, the first objective was to assess the prevalence of symptoms in the community relative to normative data. It was hypothesized that local fishers affected by the oil spill would have significant levels of depressive symptoms, anxiety, and posttraumatic symptoms compared to normative data. A second objective of this research was to identify variables which were associated with stress-responses to the spill. The COR model was used as a theoretical framework for evaluating differential consequences of the oil spill. That is, it was hypothesized that levels of resource loss would be positively correlated with levels of psychological distress. The third objective of this study involved the examination of coping strategies and psychological distress. It was hypothesized that the use of avoidant coping strategies, such as not talking about problems and trying not to think about problems, would be associated with increased symptoms of depression, anxiety, and posttraumatic stress. Finally, a comparison was made of the relative importance of resource loss versus coping strategies in predicting current psychological symptoms.

Method

Participants

Participants were recruited from fishers residing in Cordova, Alaska. Cordova is a small fishing community, with a population of 2500, located in southeastern Prince William Sound. The community is geographically isolated, accessible by boat or plane. The economy of Cordova is dominated by commercial fishing and Cordova fishers hold over 90% of the Prince William Sound fishery permits (Fried, 1994; Picou et al., 1992; Stratton, 1989). A list of members of the Cordova District Fishermen United (CDFU) in 1989 was obtained and these individuals were mailed an anonymous survey in the Fall of 1995. Five-hundred forty-one surveys were sent out, and of these, 95 were undeliverable or the individual was deceased. Of the 446 delivered surveys, 125 completed surveys were returned for a response rate of 28%.

Information on demographic characteristics of the respondents are summarized in Table 1. As is characteristic of the commercial fishing industry, the majority of respondents were male (86.4%) and were white (91.2%), with only a small percentage of women (13.6%) and Alaskan Natives (5.6%). Most of the respondents were married, had children, and had at least a high school education. The vast majority (88%) of the respondents owned their fishing vessels.

Measures

Demographic Data. Participants provided demographic data regarding gender, marital status, ethnicity, occupation, education, years in the community, household size, and household income.

Psychological Distress. Symptoms of anxiety, depression, and PTSD were assessed using the Symptom Checklist 90—Revised (SCL90-R; Derogatis, 1992). The SCL90-R is a 90-item self-report inventory designed to assess current psychological symptoms. Participants indicate on a scale from 0 to 4 the degree to which they have experienced each symptom over the past 2 weeks (0 = not at all; 4 = extremely). The complete measure was administered, however, this research

Table 1. Demographic Characteristics of Respondents ($N = 125$)

Variable	Frequency	Percentage
Gender		
Female	17	13.6
Male	108	86.4
Marital status		
Married	88	70.4
Not married	36	28.8
No response	1	0.8
Ethnicity		
White	114	91.2
Alaskan Native	7	5.6
Other	4	3.2
Occupation		
Owner	110	88.0
Skipper	6	4.8
Deckhand	1	0.8
Other	4	3.2
None	2	1.6
No response	2	1.6
Educational achievement		
Some high school	3	2.4
High school	36	28.8
Some college	53	42.4
College degree	16	12.8
Some graduate study	8	6.4
Master's degree	5	4.0
Professional degree	4	3.2
	Mean	Median
Other characteristics		
Years in community	32.8	25.0
Household size	2.8	2.0
Number of dependent children in home	1.0	0.0
1994 income	$52,000	$44,000

focused only on the subscale scores for Anxiety, Depression, and PTSD. The anxiety and depression subscales were derived by Derogatis (1992), whereas the PTSD symptoms were assessed using a subscale of the SCL90-R (Crime Related Post Traumatic Stress Disorder scale; CR-PTSD) which was devised by Saunders, Arata, and Kilpatrick (1990).

Scores on each scale were obtained by averaging the response to the items for each scale. Derogatis (1992) reported adequate test–retest and internal consistency reliability and concurrent and discriminant validity for the SCL90-R. The CR-PTSD scale has also been shown to have adequate internal consistency and concurrent validity (Arata, Saunders, & Kilpatrick, 1991; Saunders et al., 1990). Derogatis (1992) provides normative tables for a number of different populations. Nonpatient norms were used to establish a cutting score for asymptomatic versus symptomatic subjects on the Depression and Anxiety subscales.

Modified Coping Strategies Scale. Methods of coping were measured using a modified version of the Coping Strategies Scales (COSTS) developed by Beckham and Adams (1984). The original COSTS was modified in order to shorten the scale. Using a data set of 900 subjects from another study (Arata, Turnbow, & Shepard, 1996), the COSTS was modified by selecting eight items from each of three composite subscales which had the highest item–subscale correlations. The revised scales had correlations ranging from .86 to .94 with the original composite scales. Respondents were asked to complete the questionnaire based on activities they had engaged in to cope with the oil spill. Beginning with the stem, "Since the *Exxon Valdez* oil spill, I have," sample items included, "talked with friends or relatives about my problems, "felt angry but held it in," and "done something constructive." Each item was rated on a 4-point scale, where 1 = not at all, and 4 = often. Scales were scored by summing responses.

The internal consistency of the COSTS was evaluated with the current sample. The scale Emotional Expressiveness and Social Support Seeking had an alpha coefficient of .82, Emotional Containment and Passivity had an alpha coefficient of .83, and Coping Activity and Cognitive Restructuring had an alpha coefficient of .72.

Resource Loss. Indicators of resource loss were developed using items from the demographic/social data. Object resource loss was determined by four variables. Respondents answered a single question regarding whether they had been forced to sell possessions to compensate for losses due to the spill (yes/no). They also rated their perception of damage to Prince William Sound due to the oil spill (1 = no, 2 = too early to tell, 3 = yes). Respondents also gave a dollar estimate of the change in value of seining and gill fishing permits from 1989 to 1995.

Conditions resources are defined by Hobfoll as support mechanisms derived from life situations or roles in which people interact on a consistent basis, such as, job status, relationship networks, personal health, and community cohesion. Job status was assessed using a single question regarding whether the oil spill had an adverse effect on your work/occupation (yes/no). Community cohesion was similarly assessed with a single question regarding whether the spill had an adverse effect on the Cordova community (yes/no). Relationship networks were assessed using two questions regarding changes in relationships with relatives and nonrelatives. Respondents indicated on a 4-point scale whether relationships had (1) improved, (2) remained the same, (3) suffered but did not end, or (4) ended. Changes in physical health was assessed with one question rated on a 3-point scale (e.g., "Concerning your physical health, since the *Exxon Valdez* oil spill, do you perceive yourself as having (1) fewer emotional problems, (2) the same amount, or (3) more emotional problems).

Energies resources are defined as the time and money which people allocate to acquire and sustain resources. Loss of time was based on involvement in litigation regarding the oil spill (yes/no) and perceptions that litigation had been too long (yes/no). Loss of money was assessed based on the sum of reported financial losses (or gains) for each of the years since the spill (1989–1994), compared to the immediately preceding year, including 1989. "Income loss spirals" were operationalized from income loss data. Hobfoll defines a loss spiral as occurring when initial resource loss produces stress which increases future loss, which in turn, increases future stress. Individuals who reported experiencing loss of income for 3 or more of the 6 years following the spill were coded as being in an income loss spiral, while all others were categorized as not experiencing a loss spiral. Additionally, resource investment without gain was assessed by asking individuals about second jobs taken to compensate for loss. Individuals who took second jobs, yet still reported an overall economic loss, were identified as making resource investments without significant resource gain. "Income loss spiral" and "resource investment without gain" were both dichotomous variables, with 1 indicating the individual was experiencing the indicator and 0 indicating the absence of that indicator.

Procedure

Participants received an anonymous survey by mail with a cover letter explaining the nature of the research and detailing the procedures that would be used in order to help ensure the confidentiality and anonymity of results. A Certificate of Confidentiality was obtained to ensure the confidentiality of respondents' participation in the study. A Certificate of Confidentiality authorizes the withholding of the names and other identifying characteristic of the participants and helps prevent the authors from being compelled to release this information in any legal proceedings (Department of Health, Education & Welfare, 1979). An addressed, stamped envelope was included for the participants to return the completed survey. Reminder postcards were mailed on two occasions to facilitate response rates.

Results

Demographic Variables

The relationship between the psychological and the demographic variables was examined. Pearson correlation coefficients were computed for continuous demographic variables (years in the community, years of education, 1994 household income), with ANOVA used for the categorical variables (gender, marital status). Ethnicity, occupation, and household size were not included due to the limited variability in these variables. Of the demographic variables examined, the only significant relationship obtained was between years of education and depression ($r = .18$, $p < .05$).

Psychological Symptoms

Respondents' scores on the anxiety, depression, and CR-PTSD subscales of the SCL90-R were examined in relation to normative data. Participants with a T score of 70 or greater on specific subscales were categorized as symptomatic. A T score of 70 suggests that less than 2% of a normal population obtained a score equal to or higher than the designated value and is a commonly used index of clinical significance (Kaplan & Saccuzzo, 1997). As standardized normative data are not available for the CR-PTSD scale, the cutoff of .89 suggested by Saunders et al. (1990) was used to differentiate symptomatic from asymptomatic individuals. As predicted, symptoms of depression and anxiety were commonly reported problems, with 23% of men and 13% of women indicating clinically significant levels of anxiety. Clinically significant levels of depressive symptoms were reported by 39% of men and 20% of women. Similarly, symptoms of PTSD were reported by many of the respondents. Using the .89 cutoff score identified by Saunders et al. (1990), 34% of the male fishers and 40% of the female fishers endorsed a high number of PTSD-related symptoms.

Resource Loss

The relationship between resource loss and psychological symptoms was initially evaluated using Pearson correlations (see Table 2). Of the four indicators of object resource loss (selling possessions, perceived damage to the Prince William Sound, and devaluation in seining and gill net permits), having had to sell possessions was the only variable which was significantly correlated with anxiety, depression, and PTSD, with correlations ranging from .23 to .26.

Of the five indicators of conditions resource loss, significantly higher levels of anxiety were correlated with perceived negative changes in relationships with family and nonrelatives and deterioration in physical health (correlations ranging from .28 to .38). Similarly, higher levels of depression were associated with changes in relationships with family and nonrelatives, negative impact of the spill on work, and perceived deterioration in physical health (correlations ranging from .22 to .43). Finally, greater symptoms of PTSD were associated with changes in relationships with family and nonrelatives and a perceived negative impact of the spill on work and health (correlations ranging from .19 to .40).

Of the five indicators of energies resources, involvement in an income loss spiral and investment without gain manifested the strongest associations with psychological symptoms. Symptoms of anxiety were significantly associated with these two variables (.27 and .31), while symptoms of depression and PTSD were both positively correlated with investment without gain (.21 and .22), involvement in a loss spiral (.24 and .24), and involvement in litigation (.18 and .19).

Table 2. Correlations Among Resource Loss Variables, Coping Measures, and Psychological Symptoms

Variable	*M* (*SD*)	Correlation		
		Anxiety	Depression	CR-PTSD
Object resources				
Sell possessions	0.43 (0.50)	.23**	.26**	.24**
Damage to PWS	2.77 (0.57)	.17	.09	.14
Sein permit devalued	$67,777 ($108,936)	.02	−.03	−.001
Gill net permit devalued	$70,965 ($87,842)	.03	.12	.09
Conditions resources				
Relations with relatives	2.35 (0.63)	.28**	.37**	.32**
Relations with nonrelatives	2.46 (0.55)	.38**	.43**	.40**
Physical health	1.55 (0.56)	.32**	.33**	.38**
Changes at work	0.97 (0.18)	.10	.22**	.19*
Changes in community	0.95 (0.21)	.04	.02	.05
Energies resources				
Loss spiral	0.74 (0.44)	.27**	.24**	.24**
Involved in litigation	0.97 (0.18)	.07	.18*	.19*
Litigation too long	0.97 (0.18)	.04	−.11	−.03
Economic loss	−$188,550 ($349,140)	−.01	−.02	.03
Investment without gain	0.47 (0.50)	.31**	.21**	.22**
Coping				
Emotional containment/ passivity	17.42 (9.98)	.47**	.57**	.55**
Emotional expressiveness/ social support seeking	10.53 (7.91)	.37**	.24**	.26**
Coping activity/cognitive restructuring	13.31 (7.81)	.20*	.20*	.21*

*$p < .05$.
**$p < .01$.

Coping Behaviors

An additional objective of the study was to examine the relationship between coping behaviors and spill-related psychological distress (Table 2). Coping activity, emotional containment, and emotional expressiveness were all significantly correlated with each of the psychological symptom variables (correlations ranging from .20 to .57).

Coping Behaviors and Resource Loss

Multivariate analyses were used to examine the cumulative effects of resource loss and coping behaviors on psychological symptoms (Table 3). Hierarchical multiple regression analyses were calculated using each of the psychological indicators (anxiety, depression, PTSD symptoms) as criteria. Because of the large number of variables, only those which were found to have significant correlations with

Table 3. Multiple Regression

Variable	*B*	*SE B*	β	R^2
Anxiety				
Step 1 (resource loss variables)				.296***
Relations with nonrelatives	2.92	1.22	.230*	
Changes in physical health	2.67	1.07	.223*	
Investment without gain	3.41	1.29	.248**	
Step 2 (resource loss & coping variables)				.416***
Relations with nonrelatives	2.46	1.16	.193*	
Investment without gain	3.18	1.21	.231**	
Emotional containment/passivity	.19	.07	.268**	
Emotional expressiveness/social Support seeking	.28	.09	.299***	
Depression				
Step 1 (demographic variables)				.060*
Years of education	1.96	.79	.245*	
Step 2 (demographic & resource loss variables)				.395***
Relations with nonrelatives	3.88	1.79	.206*	
Changes in physical health	5.15	1.57	.290***	
Step 3 (demographic, resource loss & coping variables)				.468***
Relations with nonrelatives	3.38	1.73	.180*	
Changes in physical health	3.90	1.58	.220**	
Emotional containment/passivity	.35	.10	.336***	
Posttraumatic stress symptoms (CR-PTSD)				
Step 1 (resource loss variables)				.371***
Relations with nonrelatives	.29	.11	.250*	
Changes in physical health	.40	.10	.363**	
Investment without gain	.24	.12	.190*	
Step 2 (resource loss & coping variables)				.457***
Relations with nonrelatives	.24	.11	.203*	
Changes in physical health	.31	.10	.281**	
Emotional containment/passivity	2.21	.01	.345***	

*$p < .05$.
**$p < .01$.
***$p < .001$.

each psychological variables were included as predictors for that psychological symptom. While prior research on the COR model typically includes demographic variables in the analysis (e.g., Freedy et al., 1994), years of education was the only demographic variable which had a significant relationship to any of the criteria in the bivariate analyses, thus, it was included in the regression for depression. Resource variables were entered before coping variables in order to determine the role of coping after considering the effects of resource loss on psychological symptoms.

Anxiety. Resource loss variables accounted for 30% of the variance in anxiety symptoms, with changes in physical health, changes in relations with nonrelatives, and investment without gain making significant contributions to the model. After adding the coping variables to the equation, the final model revealed that investment without gain, changes in relations with nonrelatives, emotional containment, and emotional expressiveness predicted high levels of anxiety. These variables accounted for 42% of the variance in anxiety scores [$F(9,94) = 7.45$, $p < .0001$].

Depression. Years of education alone accounted for 6% of the variance in depression scores, however, this variable was no longer significant when resource loss variables were added to the model. When considering resource loss variables, changes in relations with nonrelatives and greater problems in health were significant predictors of symptoms of depression (39% of the variance). When the coping variables were added, changes in relations with nonrelatives, changes in health, and emotional containment were associated with increased depression. The final model accounted for 47% of the variance in depression scores [$F(11,87) = 6.96$, $p < .0001$].

PTSD Symptoms. Resource loss variables accounted for 37% of the variance in PTSD scores. Again, changes in relationships with nonrelatives, changes in physical health, and investment without gain made significant contributions to symptom levels. When the coping variables were added, changes in physical health, changes in relations with nonrelatives, and emotional containment remained in the final model. This final model accounted for 46% of the variance in CR-PTSD scores [$F(11,97) = 6.58$, $p < .001$].

Discussion

The objective of this research was an examination of the long-term psychological consequences of the *Exxon Valdez* oil spill for commercial fishers. It was hypothesized that fishers in the region of Alaska most impacted by the spill would have significant symptoms of depression, anxiety, and PTSD. The utility of the COR model for explaining chronic psychological symptoms existing 6 years after the spill was also evaluated. An analysis of the role of coping behaviors for enhancing or reducing the observed symptoms concluded the empirical analysis.

The hypothesis that the participants would have higher levels of depression, anxiety, and PTSD symptoms compared to a normative sample was supported. One-fifth of the fishers had clinically significant symptoms of anxiety and over one-third had significant symptoms of depression and/or PTSD. While the use of normative data implies that these rates are out of the ordinary for a normal population, the question can be raised regarding whether or not these symptoms can be attributed to the oil spill. The low response rate particularly leaves concern regarding a selection bias in our sample. Although we cannot rule out the threat, we think it is unlikely that selection bias explains the elevated distress observed in this sample. Findings from the 1995 survey may be compared to independent data, gathered in 1997. In the latter study, Picou, Johnson, and Gill (1997) compared psychological distress levels among adult residents in Cordova with those of Petersburg, Alaska, a community not affected by the spill. Each 1997 sample was selected using random digit dial procedures and interviews were conducted via telephone. Comparisons of mean depression scores (using SCL90-R) were made between fishing subsamples from each population. Mean depression scores were higher among Cordova fishers ($p < .05$). This test provides independent verification that distress remained unusually elevated among Cordova fishermen 8 years after the spill. At the same time, it may be argued that the normative scores used for comparisons were not appropriate for this sample. Fishers in general, or Alaskans in general, may differ in their rates of psychiatric symptoms from the general population. While control data using the same measures were not available for this study, previous research with fishers from Cordova has demonstrated that increased symptoms of PTSD and general distress were significantly higher in this community than in neighboring communities that were not as severely impacted (Picou & Gill, 1996). Thus, our findings are consistent with the trends identified in previous research.

The second objective of this study was the evaluation of the Conservation of Resources Stress model for explaining chronic psychological impacts of the spill. To the degree that we were able to operationalize the types of resources described by Hobfoll, empirical support was found for the relationship between resource loss and the persistence of chronic psychological symptoms. In the bivariate analyses, significant relationships were obtained between resource loss and symptoms of anxiety, depression, and PTSD. Conditions resource loss was found to be associated with higher levels of all psychological symptoms. In particular, deterioration in relationships with others and deterioration in physical health were both repeatedly found to predict symptoms, in both the bivariate and the multivariate analyses. Relationships with relatives and changes in work were also associated with increased symptoms in the bivariate analyses.

Energies resource loss also had a significant relationship to chronic symptoms. In the bivariate analyses, being in an "income loss spiral" was associated with greater symptoms of depression, anxiety, and PTSD. Furthermore, "investment without gain" had a significant relationship to greater symptoms in both bivariate and multivariate analyses. Thus, individuals who experienced economic loss, despite taking on additional jobs to avoid loss, were more symptomatic than those who did not experience this phenomena. This finding was particularly interesting when contrasted with the fact that economic loss alone was not a significant predictor of psychological symptoms.

Of the object resources, selling possessions was the only variable found to be significantly related to psychological symptoms. Selling possessions was associated with greater symptoms of anxiety, depression, and PTSD in the bivariate analyses but failed to make a statistically significant contribution in the multivariate analyses when other types of resource loss and coping were considered. While defined as object loss, this would seem to be similar to loss due to investment without gain; that is, individuals who were continually exhausting their efforts to compensate their losses were characterized by the most psychological symptoms.

In the bivariate analyses, each of the coping strategies was associated with higher levels of depression, anxiety, and posttraumatic symptoms. While greater distress was expected when using maladaptive coping strategies, such as emotional containment and passivity, it was expected that coping strategies which encouraged more adaptive thinking (coping activity and cognitive restructuring) would have been associated with decreased symptoms. Rather, the more distressed individuals appeared to be making use of a number of different coping strategies, some of which would seem to be opposite (emotional containment vs. emotional expressiveness). While all of the coping strategies were correlated with symptoms of distress, use of avoidant coping was found to be the best predictor of symptoms of depression, anxiety, and posttraumatic stress.

There are several interpretations relevant to our findings. First, the high rates of distress observed suggest that there have been significant long-term effects of the *Exxon Valdez* oil spill on the mental health of commercial fishers in this sample. While the limited sample makes it difficult to generalize these results, these findings are consistent with research suggesting that technological disasters produce chronic social disruption (Freudenburg & Jones, 1991). The application of the COR model helped to identify resource loss as a possible explanation for continued distress due to continuing loss of resources over time.

While there are a number of limitations to our study, the results provide empirical support for the significance of the COR framework for understanding the chronic psychological effects of disasters. Self-report data were relied on to assess losses and symptom levels and could be inaccurate or exaggerated. Norris and Kaniasty (1992), however, conducted a study of the reliability of delayed self-reports in disaster research in which they found that self-report data had high reliability. Because litigation is ongoing, there could also be concerns that individuals would be motivated to exaggerate symptoms. However, respondents were clearly informed that results were confidential and protected by a Certificate of Confidentiality obtained in order to ensure that the data would not be a part of any litigation. In fact, all criminal and civil litigation, except for appeals, had been completed at the time of our data collection. Consequently, there would have been little benefit for respondents to exaggerate symptoms for the purpose of litigation.

Another concern is whether the variables measured (social support, economic losses, etc.) were due to the oil spill and not some other factor. Certainly other events have happened since 1989 to members of this community and not all negative observations can be attributed to the oil spill. Respondents were specifically questioned regarding changes in relationships, finances, etc., that were "due to the spill," but it is possible that some of the changes could have resulted from other factors. While this may limit the ability of the study to clearly link psychological symptoms to the oil spill, the analysis supports Hobfoll's theory regarding the relationships between losses and psychological functioning. Due to the use of a cross-sectional design, the direction of causation can only be guided by the COR framework and not empirically verified.

Overall, our results indicate that the effects of the *Exxon Valdez* oil spill on the fishers in this sample have been long-lasting and appear to have been influenced by the degree to which an individual found him- or herself involved in "investment without gain" and deteriorating social support and physical health. These findings are consistent with Kaniasty and Norris' "social support deterioration model" (1993), which argues that disasters have a direct effect on mental health, but that additionally, disasters result in deterioration in social support, which leads to further deterioration in mental health. This "corrosive community" model appeared to characterize commercial fishers' response to the spill (Freudenburg & Jones, 1991). The finding of a relationship between changes in health and symptom levels supports models of stress-related illness (Evans & Edgerton, 1990; Holen, 1991). In addition to supporting the "social deterioration model" and stress–illness models, the COR stress model provided an explanatory framework for understanding the process of resource loss and chronic psychological stress for victims of a major technological disaster. Our results also demonstrate the combined roles of resource loss and coping for predicting symptoms. Deterioration in relationships and avoidant coping can be seen as reciprocal processes which exacerbate each other. That is, as relationships deteriorate, one may use more avoidant coping, which in turn, has a negative effect on relationships. Continued research is needed to identify variables which might predict which individuals and groups are most vulnerable to long-term impairment, as well as what types of interventions would be beneficial in the short and long term to prevent and ameliorate the psychological consequences of technological disasters.

Acknowledgments

This research was supported by a contract from the Prince William Sound Regional Citizen's Advisory Council. The analysis and interpretations contained in the manuscript are solely the responsibility of the authors. The authors appreciate the suggestions provided by Steve Kroll-Smith, Stephen Couch, Duane A. Gill, and Don R. South on an earlier version of this paper.

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Classics in the History of Psychology

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ISSN 1492-3713

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A Theory of Human Motivation

A. H. Maslow (1943)

Originally Published in *Psychological Review*, 50, 370-396.

Posted August 2000

[p. 370] I. INTRODUCTION

In a previous paper (13) various propositions were presented which would have to be included in any theory of human motivation that could lay claim to being definitive. These conclusions may be briefly summarized as follows:

1. The integrated wholeness of the organism must be one of the foundation stones of motivation theory.

2. The hunger drive (or any other physiological drive) was rejected as a centering point or model for a definitive theory of motivation. Any drive that is somatically based and localizable was shown to be atypical rather than typical in human motivation.

3. Such a theory should stress and center itself upon ultimate or basic goals rather than partial or superficial ones, upon ends rather than means to these ends. Such a stress would imply a more central place for unconscious than for conscious motivations.

4. There are usually available various cultural paths to the same goal. Therefore conscious, specific, local-cultural desires are not as fundamental in motivation theory as the more basic, unconscious goals.

5. Any motivated behavior, either preparatory or consummatory, must be understood to be a channel through which many basic needs may be simultaneously expressed or satisfied. Typically an act has more than one motivation.

6. Practically all organismic states are to be understood as motivated and as motivating.

7. Human needs arrange themselves in hierarchies of pre-potency. That is to say, the appearance of one need usually rests on the prior satisfaction of another, more pre-potent need. Man is a perpetually wanting animal. Also no need or drive can be treated as if it were isolated or discrete; every drive is related to the state of satisfaction or dissatisfaction of other drives.

8. *Lists* of drives will get us nowhere for various theoretical and practical reasons. Furthermore any classification of motivations [p. 371] must deal with the problem of levels of specificity or generalization the motives to be classified.

9. Classifications of motivations must be based upon goals rather than upon instigating drives or motivated behavior.

10. Motivation theory should be human-centered rather than animal-centered.

11. The situation or the field in which the organism reacts must be taken into account but the field alone can rarely serve as an exclusive explanation for behavior. Furthermore the field itself must be interpreted in terms of the organism. Field theory cannot be a substitute for motivation theory.

12. Not only the integration of the organism must be taken into account, but also the possibility of isolated, specific, partial or segmental reactions. It has since become necessary to add to these another affirmation.

13. Motivation theory is not synonymous with behavior theory. The motivations are only one class of determinants of behavior. While behavior is almost always motivated, it is also almost always biologically, culturally and situationally determined as well.

The present paper is an attempt to formulate a positive theory of motivation which will satisfy these theoretical demands and at the same time conform to the known facts, clinical and observational as well as experimental. It derives most directly, however, from clinical experience. This theory is, I think, in the functionalist tradition of James and Dewey, and is fused with the holism of Wertheimer (19), Goldstein (6), and Gestalt Psychology, and with the dynamicism of Freud (4) and Adler (1). This fusion or synthesis may arbitrarily be called a 'general-dynamic' theory.

It is far easier to perceive and to criticize the aspects in motivation theory than to remedy them. Mostly this is because of the very serious lack of sound data in this area. I conceive this lack of sound facts to be due primarily to the absence of a valid theory of motivation. The present theory then must be considered to be a suggested program or framework for future research and must stand or fall, not so much on facts available or evidence presented, as upon researches to be done, researches suggested perhaps, by the questions raised in this paper.[p. 372]

II. THE BASIC NEEDS

The 'physiological' needs. -- The needs that are usually taken as the starting point for motivation theory are the so-called physiological drives. Two recent lines of research make it necessary to revise our customary notions about these needs, first, the development of the concept of homeostasis, and second, the finding that appetites (preferential choices among foods) are a fairly efficient indication of actual needs or lacks in the body.

Homeostasis refers to the body's automatic efforts to maintain a constant, normal state of the blood stream. Cannon (2) has described this process for (1) the water content of the blood, (2) salt content, (3) sugar content, (4) protein content, (5) fat content, (6) calcium content, (7) oxygen content, (8) constant hydrogen-ion level (acid-base balance) and (9) constant temperature of the blood. Obviously this list can be extended to include other minerals, the hormones, vitamins, etc.

Young in a recent article (21) has summarized the work on appetite in its relation to body needs. If the body lacks some chemical, the individual will tend to develop a specific appetite or partial hunger for that food element.

Thus it seems impossible as well as useless to make any list of fundamental physiological needs for they can come to almost any number one might wish, depending on the degree of specificity of description. We cannot identify all physiological needs as homeostatic. That sexual desire, sleepiness, sheer activity and maternal behavior in animals, are homeostatic, has not yet been demonstrated. Furthermore, this list would not include the various sensory pleasures (tastes, smells, tickling, stroking) which are probably physiological and which may become the goals of motivated behavior.

In a previous paper (13) it has been pointed out that these physiological drives or needs are to be considered unusual rather than typical because they are isolable, and because they are localizable somatically. That is to say, they are relatively independent of each other, of other motivations [p. 373] and of the organism as a whole, and secondly, in many cases, it is possible to demonstrate a localized, underlying somatic base for the drive. This is true less generally than has been thought (exceptions are fatigue, sleepiness, and maternal responses) but it is still true in the classic instances of hunger, sex, and thirst.

It should be pointed out again that any of the physiological needs and the consummatory behavior involved with them serve as channels for all sorts of other needs as well. That is to say, the person who thinks he is hungry may actually be seeking more for comfort, or dependence, than for vitamins or proteins. Conversely, it is possible to satisfy the hunger need in part by other activities such as drinking water or smoking cigarettes. In other words, relatively isolable as these physiological needs are, they are not completely so.

Undoubtedly these physiological needs are the most pre-potent of all needs. What this means specifically is, that in the human being who is missing everything in life in an extreme fashion, it is most likely that the major motivation would be the physiological needs rather than any others.

A person who is lacking food, safety, love, and esteem would most probably hunger for food more strongly than for anything else.

If all the needs are unsatisfied, and the organism is then dominated by the physiological needs, all other needs may become simply non-existent or be pushed into the background. It is then fair to characterize the whole organism by saying simply that it is hungry, for consciousness is almost completely preempted by hunger. All capacities are put into the service of hunger-satisfaction, and the organization of these capacities is almost entirely determined by the one purpose of satisfying hunger. The receptors and effectors, the intelligence, memory, habits, all may now be defined simply as hunger-gratifying tools. Capacities that are not useful for this purpose lie dormant, or are pushed into the background. The urge to write poetry, the desire to acquire an automobile, the interest in American history, the desire for a new pair of shoes are, in the extreme case, forgotten or become of sec-[p.374]ondary importance. For the man who is extremely and dangerously hungry, no other interests exist but food. He dreams food, he remembers food, he thinks about food, he emotes only about food, he perceives only food and he wants only food. The more subtle determinants that ordinarily fuse with the physiological drives in organizing even feeding, drinking or sexual behavior, may now be so completely overwhelmed as to allow us to speak at this time (but only at this time) of pure hunger drive and behavior, with the one unqualified aim of relief.

Another peculiar characteristic of the human organism when it is dominated by a certain need is that the whole philosophy of the future tends also to change. For our chronically and extremely hungry man, Utopia can be defined very simply as a place where there is plenty of food. He tends to think that, if only he is guaranteed food for the rest of his life, he will be perfectly happy and will never want anything more. Life itself tends to be defined in terms of eating. Anything else will be defined as unimportant. Freedom, love, community feeling, respect, philosophy, may all be waved aside as fripperies which are useless since they fail to fill the stomach. Such a man may fairly be said to live by bread alone.

It cannot possibly be denied that such things are true but their *generality* can be denied. Emergency conditions are, almost by definition, rare in the normally functioning peaceful society. That this truism can be forgotten is due mainly to two reasons. First, rats have few motivations other than physiological ones, and since so much of the research upon motivation has been made with these animals, it is easy to carry the rat-picture over to the human being. Secondly, it is too often not realized that culture itself is an adaptive tool, one of whose main functions is to make the physiological emergencies come less and less often. In most of the known societies, chronic extreme hunger of the emergency type is rare, rather than common. In any case, this is still true in the United States. The average American citizen is experiencing appetite rather than hunger when he says "I am [p. 375] hungry." He is apt to experience sheer life-and-death hunger only by accident and then only a few times through his entire life.

Obviously a good way to obscure the 'higher' motivations, and to get a lopsided view of human capacities and human nature, is to make the organism extremely and chronically hungry or thirsty. Anyone who attempts to make an emergency picture into a typical one, and who will measure all of man's goals and desires by his behavior during extreme physiological deprivation is certainly being blind to many things. It is quite true that man lives by bread alone -- when there is no bread. But what happens to man's desires when there is plenty of bread and when his belly is chronically filled?

At once other (and 'higher') needs emerge and these, rather than physiological hungers, dominate the organism. And when these in turn are satisfied, again new (and still 'higher') needs emerge and so on. This is what we mean by saying that the basic human needs are organized into a hierarchy of relative prepotency.

One main implication of this phrasing is that gratification becomes as important a concept as deprivation in motivation theory, for it releases the organism from the domination of a relatively more physiological need, permitting thereby the emergence of other more social goals. The physiological needs, along with their partial goals, when chronically gratified cease to exist as active determinants or organizers of behavior. They now exist only in a potential fashion in the sense that they may emerge again to dominate the organism if they are thwarted. But a want that is satisfied is no longer a want. The organism is dominated and its behavior organized only by unsatisfied needs. If hunger is satisfied, it becomes unimportant in the current dynamics of the individual.

This statement is somewhat qualified by a hypothesis to be discussed more fully later, namely that it is precisely those individuals in whom a certain need has always been satisfied who are best equipped to tolerate deprivation of that need in the future, and that furthermore, those who have been de-[p. 376]prived in the past will react differently to current satisfactions than the one who has never been deprived.

The safety needs. -- If the physiological needs are relatively well gratified, there then emerges a new set of needs, which we may categorize roughly as the safety needs. All that has been said of the physiological needs is equally true, although in lesser degree, of these desires. The organism may equally well be wholly dominated by them. They may serve as the almost exclusive organizers of behavior, recruiting all the capacities of the organism in their service, and we may then fairly describe the whole organism as a safety-seeking mechanism. Again we may say of the receptors, the effectors, of the intellect and the other capacities that they are primarily safety-seeking tools. Again, as in the hungry man, we find that the dominating goal is a strong determinant not only of his current world-outlook and philosophy but also of his philosophy of the future. Practically everything looks less important than safety, (even sometimes the physiological needs which being satisfied, are now underestimated). A man, in this state, if it is extreme enough and chronic enough, may be characterized as living almost for safety alone.

Although in this paper we are interested primarily in the needs of the adult, we can approach an understanding of his safety needs perhaps more efficiently by observation of infants and children, in whom these needs are much more simple and obvious. One reason for the clearer appearance of the threat or danger reaction in infants, is that they do not inhibit this reaction at all, whereas adults in our society have been taught to inhibit it at all costs. Thus even when adults do feel their safety to be threatened we may not be able to see this on the surface. Infants will react in a total fashion and as if they were endangered, if they are disturbed or dropped suddenly, startled by loud noises, flashing light, or other unusual sensory stimulation, by rough handling, by general loss of support in the mother's arms, or by inadequate support.[1][p. 377]

In infants we can also see a much more direct reaction to bodily illnesses of various kinds. Sometimes these illnesses seem to be immediately and *per se* threatening and seem to make the child feel unsafe. For instance, vomiting, colic or other sharp pains seem to make the child look at the whole world in a different way. At such a moment of pain, it may be postulated that, for the child, the appearance of the whole world suddenly changes from sunniness to darkness, so to speak, and becomes a place in which anything at all might happen, in which previously stable things have suddenly become unstable. Thus a child who because of some bad food is taken ill may, for a day or two, develop fear, nightmares, and a need for protection and reassurance never seen in him before his illness.

Another indication of the child's need for safety is his preference for some kind of undisrupted routine or rhythm. He seems to want a predictable, orderly world. For instance, injustice, unfairness, or inconsistency in the parents seems to make a child feel anxious and unsafe. This attitude may be not so much because of the injustice *per se* or any particular pains involved, but rather because this treatment threatens to make the world look unreliable, or unsafe, or unpredictable. Young children seem to thrive better under a system which has at least a skeletal outline of rigidity, In which there is a schedule of a kind, some sort of routine, something that can be counted upon, not only for the present but also far into the future. Perhaps one could express this more accurately by saying that the child needs an organized world rather than an unorganized or unstructured one.

The central role of the parents and the normal family setup are indisputable. Quarreling, physical assault, separation, divorce or death within the family may be particularly terrifying. Also parental outbursts of rage or threats of punishment directed to the child, calling him names, speaking to him harshly, shaking him, handling him roughly, or actual [p. 378] physical punishment sometimes elicit such total panic and terror in the child that we must assume more is involved than the physical pain alone. While it is true that in some children this terror may represent also a fear of loss of parental love, it can also occur in completely rejected children, who seem to cling to the hating parents more for sheer safety and protection than because of hope of love.

Confronting the average child with new, unfamiliar, strange, unmanageable stimuli or situations will too frequently elicit the danger or terror reaction, as for example, getting lost or even being separated from the parents for a short time, being confronted with new faces, new situations or new tasks, the sight of strange, unfamiliar or uncontrollable objects, illness or death. Particularly at such times, the child's frantic clinging to his parents is eloquent testimony to their role as protectors (quite apart from their roles as food-givers and love-givers).

From these and similar observations, we may generalize and say that the average child in our society generally prefers a safe, orderly, predictable, organized world, which he can count, on, and in which unexpected, unmanageable or other dangerous things do not happen, and in which, in any case, he has all-powerful parents who protect and shield him from harm.

That these reactions may so easily be observed in children is in a way a proof of the fact that children in our society, feel too unsafe (or, in a word, are badly brought up). Children who are reared in an unthreatening, loving family do not ordinarily react as we have described above

(17). In such children the danger reactions are apt to come mostly to objects or situations that adults too would consider dangerous.[2]

The healthy, normal, fortunate adult in our culture is largely satisfied in his safety needs. The peaceful, smoothly [p. 379] running, 'good' society ordinarily makes its members feel safe enough from wild animals, extremes of temperature, criminals, assault and murder, tyranny, etc. Therefore, in a very real sense, he no longer has any safety needs as active motivators. Just as a sated man no longer feels hungry, a safe man no longer feels endangered. If we wish to see these needs directly and clearly we must turn to neurotic or near-neurotic individuals, and to the economic and social underdogs. In between these extremes, we can perceive the expressions of safety needs only in such phenomena as, for instance, the common preference for a job with tenure and protection, the desire for a savings account, and for insurance of various kinds (medical, dental, unemployment, disability, old age).

Other broader aspects of the attempt to seek safety and stability in the world are seen in the very common preference for familiar rather than unfamiliar things, or for the known rather than the unknown. The tendency to have some religion or world-philosophy that organizes the universe and the men in it into some sort of satisfactorily coherent, meaningful whole is also in part motivated by safety-seeking. Here too we may list science and philosophy in general as partially motivated by the safety needs (we shall see later that there are also other motivations to scientific, philosophical or religious endeavor).

Otherwise the need for safety is seen as an active and dominant mobilizer of the organism's resources only in emergencies, *e. g*., war, disease, natural catastrophes, crime waves, societal disorganization, neurosis, brain injury, chronically bad situation.

Some neurotic adults in our society are, in many ways, like the unsafe child in their desire for safety, although in the former it takes on a somewhat special appearance. Their reaction is often to unknown, psychological dangers in a world that is perceived to be hostile, overwhelming and threatening. Such a person behaves as if a great catastrophe were almost always impending, i.e., he is usually responding as if to an emergency. His safety needs often find specific [p. 380] expression in a search for a protector, or a stronger person on whom he may depend, or perhaps, a Fuehrer.

The neurotic individual may be described in a slightly different way with some usefulness as a grown-up person who retains his childish attitudes toward the world. That is to say, a neurotic adult may be said to behave 'as if' he were actually afraid of a spanking, or of his mother's disapproval, or of being abandoned by his parents, or having his food taken away from him. It is as if his childish attitudes of fear and threat reaction to a dangerous world had gone underground, and untouched by the growing up and learning processes, were now ready to be called out by any stimulus that would make a child feel endangered and threatened.[3]

The neurosis in which the search for safety takes its dearest form is in the compulsive-obsessive neurosis. Compulsive-obsessives try frantically to order and stabilize the world so that no unmanageable, unexpected or unfamiliar dangers will ever appear (14); They hedge themselves about with all sorts of ceremonials, rules and formulas so that every possible contingency may be provided for and so that no new contingencies may appear. They are much like the brain injured cases, described by Goldstein (6), who manage to maintain their equilibrium by avoiding everything unfamiliar and strange and by ordering their restricted world in such a neat, disciplined, orderly fashion that everything in the world can be counted upon. They try to arrange the world so that anything unexpected (dangers) cannot possibly occur. If, through no fault of their own, something unexpected does occur, they go into a panic reaction as if this unexpected occurrence constituted a grave danger. What we can see only as a none-too-strong preference in the healthy person, *e. g*., preference for the familiar, becomes a life-and-death. necessity in abnormal cases.

The love needs. -- If both the physiological and the safety needs are fairly well gratified, then there will emerge the love and affection and belongingness needs, and the whole cycle [p. 381] already described will repeat itself with this new center. Now the person will feel keenly, as never before, the absence of friends, or a sweetheart, or a wife, or children. He will hunger for affectionate relations with people in general, namely, for a place in his group, and he will strive with great intensity to achieve this goal. He will want to attain such a place more than anything else in the world and may even forget that once, when he was hungry, he sneered at love.

In our society the thwarting of these needs is the most commonly found core in cases of maladjustment and more severe psychopathology. Love and affection, as well as their possible expression in sexuality, are generally looked upon with ambivalence and are customarily hedged about with many restrictions and inhibitions. Practically all theorists of psychopathology have stressed thwarting of the love needs as basic in the picture of maladjustment. Many clinical studies have therefore been made of this need and we know more about it perhaps than any of the other needs except the physiological ones (14).

One thing that must be stressed at this point is that love is not synonymous with sex. Sex may be studied as a purely physiological need. Ordinarily sexual behavior is multi-determined, that is to say, determined not only by sexual but also by other needs, chief among which are the love and affection needs. Also not to be overlooked is the fact that the love needs involve both giving *and* receiving love.[4]

The esteem needs. -- All people in our society (with a few pathological exceptions) have a need or desire for a stable, firmly based, (usually) high evaluation of themselves, for self-respect, or self-esteem, and for the esteem of others. By firmly based self-esteem, we mean that which is soundly based upon real capacity, achievement and respect from others. These needs may be classified into two subsidiary sets. These are, first, the desire for strength, for achievement, for adequacy, for confidence in the face of the world, and for independence and freedom.[5] Secondly, we have what [p. 382] we may call the desire for reputation or prestige (defining it as respect or esteem from other people), recognition, attention, importance or appreciation.[6] These needs have been relatively stressed by Alfred Adler and his followers, and have been relatively neglected by Freud and the psychoanalysts. More and more today however there is appearing widespread appreciation of their central importance.

Satisfaction of the self-esteem need leads to feelings of self-confidence, worth, strength, capability and adequacy of being useful and necessary in the world. But thwarting of these needs produces feelings of inferiority, of weakness and of helplessness. These feelings in turn give rise to either basic discouragement or else compensatory or neurotic trends. An appreciation of the necessity of basic self-confidence and an understanding of how helpless people are without it, can be easily gained from a study of severe traumatic neurosis (8).[7]

The need for self-actualization. -- Even if all these needs are satisfied, we may still often (if not always) expect that a new discontent and restlessness will soon develop, unless the individual is doing what he is fitted for. A musician must make music, an artist must paint, a poet must write, if he is to be ultimately happy. What a man *can* be, he *must* be. This need we may call self-actualization.

This term, first coined by Kurt Goldstein, is being used in this paper in a much more specific and limited fashion. It refers to the desire for self-fulfillment, namely, to the tendency for him to become actualized in what he is potentially. This tendency might be phrased as the desire to become more and more what one is, to become everything that one is capable of becoming.[p. 383]

The specific form that these needs will take will of course vary greatly from person to person. In one individual it may take the form of the desire to be an ideal mother, in another it may be expressed athletically, and in still another it may be expressed in painting pictures or in inventions. It is not necessarily a creative urge although in people who have any capacities for creation it will take this form.

The clear emergence of these needs rests upon prior satisfaction of the physiological, safety, love and esteem needs. We shall call people who are satisfied in these needs, basically satisfied people, and it is from these that we may expect the fullest (and healthiest) creativeness.[8] Since, in our society, basically satisfied people are the exception, we do not know much about self-actualization, either experimentally or clinically. It remains a challenging problem for research.

The preconditions for the basic need satisfactions. -- There are certain conditions which are immediate prerequisites for the basic need satisfactions. Danger to these is reacted to almost as if it were a direct danger to the basic needs themselves. Such conditions as freedom to speak, freedom to do what one wishes so long as no harm is done to others, freedom to express one's self, freedom to investigate and seek for information, freedom to defend one's self, justice, fairness, honesty, orderliness in the group are examples of such preconditions for basic need satisfactions. Thwarting in these freedoms will be reacted to with a threat or emergency response. These conditions are not ends in themselves but they are *almost* so since they are so closely related to the basic needs, which are apparently the only ends in themselves. These conditions are defended because without them the basic satisfactions are quite impossible, or at least, very severely endangered.[p. 384]

If we remember that the cognitive capacities (perceptual, intellectual, learning) are a set of adjustive tools, which have, among other functions, that of satisfaction of our basic needs, then it is clear that any danger to them, any deprivation or blocking of their free use, must also be indirectly threatening to the basic needs themselves. Such a statement is a partial solution of the general problems of curiosity, the search for knowledge, truth and wisdom, and the ever-persistent urge to solve the cosmic mysteries.

We must therefore introduce another hypothesis and speak of degrees of closeness to the basic needs, for we have already pointed out that *any* conscious desires (partial goals) are more or less important as they are more or less close to the basic needs. The same statement may be made for various behavior acts. An act is psychologically important if it contributes directly to satisfaction of basic needs. The less directly it so contributes, or the weaker this contribution is, the less important this act must be conceived to be from the point of view of dynamic psychology. A similar statement may be made for the various defense or coping mechanisms. Some are very directly related to the protection or attainment of the basic needs, others are only weakly and distantly related. Indeed if we wished, we could speak of more basic and less basic defense mechanisms, and then affirm that danger to the more basic defenses is more threatening than danger to less basic defenses (always remembering that this is so only because of their relationship to the basic needs).

The desires to know and to understand. -- So far, we have mentioned the cognitive needs only in passing. Acquiring knowledge and systematizing the universe have been considered as, in part, techniques for the achievement of basic safety in the world, or, for the intelligent man, expressions of self-actualization. Also freedom of inquiry and expression have been discussed as preconditions of satisfactions of the basic needs. True though these formulations may be, they do not constitute definitive answers to the question as to the motivation role of curiosity, learning, philosophizing, experimenting, etc. They are, at best, no more than partial answers.[p. 385]

This question is especially difficult because we know so little about the facts. Curiosity, exploration, desire for the facts, desire to know may certainly be observed easily enough. The fact that they often are pursued even at great cost to the individual's safety is an earnest of the partial character of our previous discussion. In addition, the writer must admit that, though he has sufficient clinical evidence to postulate the desire to know as a very strong drive in intelligent people, no data are available for unintelligent people. It may then be largely a function of relatively high intelligence. Rather tentatively, then, and largely in the hope of stimulating discussion and research, we shall postulate a basic desire to know, to be aware of reality, to get the facts, to satisfy curiosity, or as Wertheimer phrases it, to see rather than to be blind.

This postulation, however, is not enough. Even after we know, we are impelled to know more and more minutely and microscopically on the one hand, and on the other, more and more extensively in the direction of a world philosophy, religion, etc. The facts that we acquire, if they are isolated or atomistic, inevitably get theorized about, and either analyzed or organized or both. This process has been phrased by some as the search for 'meaning.' We shall then postulate a desire to understand, to systematize, to organize, to analyze, to look for relations and meanings.

Once these desires are accepted for discussion, we see that they too form themselves into a small hierarchy in which the desire to know is prepotent over the desire to understand. All the characteristics of a hierarchy of prepotency that we have described above, seem to hold for this one as well.

We must guard ourselves against the too easy tendency to separate these desires from the basic needs we have discussed above, *i.e*., to make a sharp dichotomy between 'cognitive' and 'conative' needs. The desire to know and to understand are themselves conative, i.e., have a striving character, and are as much personality needs as the 'basic needs' we have already discussed (19).[p. 386]

III. FURTHER CHARACTERISTICS OF THE BASIC NEEDS

The degree of fixity of the hierarchy of basic needs. -- We have spoken so far as if this hierarchy were a fixed order but actually it is not nearly as rigid as we may have implied. It is true that most of the people with whom we have worked have seemed to have these basic needs in about the order that has been indicated. However, there have been a number of exceptions.

(1) There are some people in whom, for instance, self-esteem seems to be more important than love. This most common reversal in the hierarchy is usually due to the development of the notion that the person who is most likely to be loved is a strong or powerful person, one who inspires respect or fear, and who is self confident or aggressive. Therefore such people who lack love and seek it, may try hard to put on a front of aggressive, confident behavior. But essentially they seek high self-esteem and its behavior expressions more as a means-to-an-end than for its own sake; they seek self-assertion for the sake of love rather than for self-esteem itself.

(2) There are other, apparently innately creative people in whom the drive to creativeness seems to be more important than any other counter-determinant. Their creativeness might appear not as self-actualization released by basic satisfaction, but in spite of lack of basic satisfaction.

(3) In certain people the level of aspiration may be permanently deadened or lowered. That is to say, the less pre-potent goals may simply be lost, and may disappear forever, so that the person who has experienced life at a very low level, *i. e*., chronic unemployment, may continue to be satisfied for the rest of his life if only he can get enough food.

(4) The so-called 'psychopathic personality' is another example of permanent loss of the love needs. These are people who, according to the best data available (9), have been starved for love in the earliest months of their lives and have simply lost forever the desire and the ability to give and to receive affection (as animals lose sucking or pecking reflexes that are not exercised soon enough after birth).[p. 387]

(5) Another cause of reversal of the hierarchy is that when a need has been satisfied for a long time, this need may be underevaluated. People who have never experienced chronic hunger are apt to underestimate its effects and to look upon food as a rather unimportant thing. If they are dominated by a higher need, this higher need will seem to be the most important of all. It then becomes possible, and indeed does actually happen, that they may, for the sake of this higher need, put themselves into the position of being deprived in a more basic need. We may expect that after a long-time deprivation of the more basic need there will be a tendency to reevaluate both needs so that the more pre-potent need will actually become consciously prepotent for the individual who may have given it up very lightly. Thus, a man who has given up his job rather

than lose his self-respect, and who then starves for six months or so, may be willing to take his job back even at the price of losing his a self-respect.

(6) Another partial explanation of *apparent* reversals is seen in the fact that we have been talking about the hierarchy of prepotency in terms of consciously felt wants or desires rather than of behavior. Looking at behavior itself may give us the wrong impression. What we have claimed is that the person will want the more basic of two needs when deprived in both. There is no necessary implication here that he will act upon his desires. Let us say again that there are many determinants of behavior other than the needs and desires.

(7) Perhaps more important than all these exceptions are the ones that involve ideals, high social standards, high values and the like. With such values people become martyrs; they give up everything for the sake of a particular ideal, or value. These people may be understood, at least in part, by reference to one basic concept (or hypothesis) which may be called 'increased frustration-tolerance through early gratification'. People who have been satisfied in their basic needs throughout their lives, particularly in their earlier years, seem to develop exceptional power to withstand present or future thwarting of these needs simply because they have strong,[p. 388] healthy character structure as a result of basic satisfaction. They are the 'strong' people who can easily weather disagreement or opposition, who can swim against the stream of public opinion and who can stand up for the truth at great personal cost. It is just the ones who have loved and been well loved, and who have had many deep friendships who can hold out against hatred, rejection or persecution.

I say all this in spite of the fact that there is a certain amount of sheer habituation which is also involved in any full discussion of frustration tolerance. For instance, it is likely that those persons who have been accustomed to relative starvation for a long time, are partially enabled thereby to withstand food deprivation. What sort of balance must be made between these two tendencies, of habituation on the one hand, and of past satisfaction breeding present frustration tolerance on the other hand, remains to be worked out by further research. Meanwhile we may assume that they are both operative, side by side, since they do not contradict each other, In respect to this phenomenon of increased frustration tolerance, it seems probable that the most important gratifications come in the first two years of life. That is to say, people who have been made secure and strong in the earliest years, tend to remain secure and strong thereafter in the face of whatever threatens.

Degree of relative satisfaction. -- So far, our theoretical discussion may have given the impression that these five sets of needs are somehow in a step-wise, all-or-none relationships to each other. We have spoken in such terms as the following: "If one need is satisfied, then another emerges." This statement might give the false impression that a need must be satisfied 100 per cent before the next need emerges. In actual fact, most members of our society who are normal, are partially satisfied in all their basic needs and partially unsatisfied in all their basic needs at the same time. A more realistic description of the hierarchy would be in terms of decreasing percentages of satisfaction as we go up the hierarchy of prepotency, For instance, if I may assign arbitrary figures for the sake of illustration, it is as if the average citizen [p. 389] is satisfied perhaps 85 per cent in his physiological needs, 70 per cent in his safety needs, 50 per cent in his love needs, 40 per cent in his self-esteem needs, and 10 per cent in his self-actualization needs.

As for the concept of emergence of a new need after satisfaction of the prepotent need, this emergence is not a sudden, saltatory phenomenon but rather a gradual emergence by slow degrees from nothingness. For instance, if prepotent need A is satisfied only 10 per cent: then need B may not be visible at all. However, as this need A becomes satisfied 25 per cent, need B may emerge 5 per cent, as need A becomes satisfied 75 per cent need B may emerge go per cent, and so on.

Unconscious character of needs. -- These needs are neither necessarily conscious nor unconscious. On the whole, however, in the average person, they are more often unconscious rather than conscious. It is not necessary at this point to overhaul the tremendous mass of evidence which indicates the crucial importance of unconscious motivation. It would by now be expected, on a priori grounds alone, that unconscious motivations would on the whole be rather more important than the conscious motivations. What we have called the basic needs are very often largely unconscious although they may, with suitable techniques, and with sophisticated people become conscious.

Cultural specificity and generality of needs. -- This classification of basic needs makes some attempt to take account of the relative unity behind the superficial differences in specific desires from one culture to another. Certainly in any particular culture an individual's conscious motivational content will usually be extremely different from the conscious motivational content of an individual in another society. However, it is the common experience of anthropologists that people, even in different societies, are much more alike than we would think from our first contact with them, and that as we know them better we seem to find more and more of this commonness, We then recognize the most startling differences to be superficial rather than basic, *e. g*., differences in style of hair-dress, clothes, tastes in food, etc. Our classification of basic [p. 390] needs is in part an attempt to account for this unity behind the apparent diversity from culture to culture. No claim is made that it is ultimate or universal for all cultures. The claim is made only that it is relatively *more* ultimate, more universal, more basic, than the superficial conscious desires from culture to culture, and makes a somewhat closer approach to common-human characteristics, Basic needs are *more* common-human than superficial desires or behaviors.

Multiple motivations of behavior. -- These needs must be understood not to be *exclusive* or single determiners of certain kinds of behavior. An example may be found in any behavior that seems to be physiologically motivated, such as eating, or sexual play or the like. The clinical psychologists have long since found that any behavior may be a channel through which flow various determinants. Or to say it in another way, most behavior is multi-motivated. Within the sphere of motivational determinants any behavior tends to be determined by several or *all* of the basic needs simultaneously rather than by only one of them. The latter would be more an exception than the former. Eating may be partially for the sake of filling the stomach, and partially for the sake of comfort and amelioration of other needs. One may make love not only for pure sexual release, but also to convince one's self of one's masculinity, or to make a conquest, to feel powerful, or to win more basic affection. As an illustration, I may point out that it would be possible (theoretically if not practically) to analyze a single act of an individual and see in it the expression of his physiological needs, his safety needs, his love needs, his esteem needs and self-actualization. This contrasts sharply with the more naive brand of trait psychology in which one trait or one motive accounts for a certain kind of act, *i. e.*, an aggressive act is traced solely to a trait of aggressiveness.

Multiple determinants of behavior. -- Not all behavior is determined by the basic needs. We might even say that not all behavior is motivated. There are many determinants of behavior other than motives.[9] For instance, one other im-[p. 391]portant class of determinants is the so-called 'field' determinants. Theoretically, at least, behavior may be determined completely by the field, or even by specific isolated external stimuli, as in association of ideas, or certain conditioned reflexes. If in response to the stimulus word 'table' I immediately perceive a memory image of a table, this response certainly has nothing to do with my basic needs.

Secondly, we may call attention again to the concept of 'degree of closeness to the basic needs' or 'degree of motivation.' Some behavior is highly motivated, other behavior is only weakly motivated. Some is not motivated at all (but all behavior is determined).

Another important point [10] is that there is a basic difference between expressive behavior and coping behavior (functional striving, purposive goal seeking). An expressive behavior does not try to do anything; it is simply a reflection of the personality. A stupid man behaves stupidly, not because he wants to, or tries to, or is motivated to, but simply because he is what he is. The same is true when I speak in a bass voice rather than tenor or soprano. The random movements of a healthy child, the smile on the face of a happy man even when he is alone, the springiness of the healthy man's walk, and the erectness of his carriage are other examples of expressive, non-functional behavior. Also the *style* in which a man carries out almost all his behavior, motivated as well as unmotivated, is often expressive.

We may then ask, is *all* behavior expressive or reflective of the character structure? The answer is 'No.' Rote, habitual, automatized, or conventional behavior may or may not be expressive. The same is true for most 'stimulus-bound' behaviors. It is finally necessary to stress that expressiveness of behavior, and goal-directedness of behavior are not mutually exclusive categories. Average behavior is usually both.

Goals as centering principle in motivation theory. -- It will be observed that the basic principle in our classification has [p. 392] been neither the instigation nor the motivated behavior but rather the functions, effects, purposes, or goals of the behavior. It has been proven sufficiently by various people that this is the most suitable point for centering in any motivation theory.[11]

Animal- and human-centering. -- This theory starts with the human being rather than any lower and presumably 'simpler' animal. Too many of the findings that have been made in animals have been proven to be true for animals but not for the human being. There is no reason whatsoever why we should start with animals in order to study human motivation. The logic or rather illogic behind this general fallacy of 'pseudo-simplicity' has been exposed often enough by philosophers and logicians as well as by scientists in each of the various fields. It is no more necessary to study animals before one can study man than it is to study mathematics before one can study geology or psychology or biology.

We may also reject the old, naive, behaviorism which assumed that it was somehow necessary, or at least more 'scientific' to judge human beings by animal standards. One consequence of this belief was that the whole notion of purpose and goal was excluded from motivational psychology simply because one could not ask a white rat about his purposes. Tolman (18) has long since proven in animal studies themselves that this exclusion was not necessary.

Motivation and the theory of psychopathogenesis. -- The conscious motivational content of everyday life has, according to the foregoing, been conceived to be relatively important or unimportant accordingly as it is more or less closely related to the basic goals. A desire for an ice cream cone might actually be an indirect expression of a desire for love. If it is, then this desire for the ice cream cone becomes extremely important motivation. If however the ice cream is simply something to cool the mouth with, or a casual appetitive reaction, then the desire is relatively unimportant. Everyday conscious desires are to be regarded as symptoms, as [p. 393] *surface indicators of more basic needs*. If we were to take these superficial desires at their face value me would find ourselves in a state of complete confusion which could never be resolved, since we would be dealing seriously with symptoms rather than with what lay behind the symptoms.

Thwarting of unimportant desires produces no psychopathological results; thwarting of a basically important need does produce such results. Any theory of psychopathogenesis must then be based on a sound theory of motivation. A conflict or a frustration is not necessarily pathogenic. It becomes so only when it threatens or thwarts the basic needs, or partial needs that are closely related to the basic needs (10).

The role of gratified needs. -- It has been pointed out above several times that our needs usually emerge only when more prepotent needs have been gratified. Thus gratification has an important role in motivation theory. Apart from this, however, needs cease to play an active determining or organizing role as soon as they are gratified.

What this means is that, *e. g.*, a basically satisfied person no longer has the needs for esteem, love, safety, etc. The only sense in which he might be said to have them is in the almost metaphysical sense that a sated man has hunger, or a filled bottle has emptiness. If we are interested in what *actually* motivates us, and not in what has, will, or might motivate us, then a satisfied need is not a motivator. It must be considered for all practical purposes simply not to exist, to have disappeared. This point should be emphasized because it has been either overlooked or contradicted in every theory of motivation I know.[12] The perfectly healthy, normal, fortunate man has no sex needs or hunger needs, or needs for safety, or for love, or for prestige, or self-esteem, except in stray moments of quickly passing threat. If we were to say otherwise, we should also have to aver that every man had all the pathological reflexes, *e. g.*, Babinski, etc., because if his nervous system were damaged, these would appear.

It is such considerations as these that suggest the bold [p. 394] postulation that a man who is thwarted in any of his basic needs may fairly be envisaged simply as a sick man. This is a fair parallel to our designation as 'sick' of the man who lacks vitamins or minerals. Who is to say that a lack of love is less important than a lack of vitamins? Since we know the pathogenic effects of love starvation, who is to say that we are invoking value-questions in an unscientific or illegitimate way, any more than the physician does who diagnoses and treats pellagra or scurvy? If I were permitted this usage, I should then say simply that a healthy man is primarily motivated by his needs to develop and actualize his fullest potentialities and capacities. If a man has any other basic needs in any active, chronic sense, then he is simply an unhealthy man. He is as surely sick as if he had suddenly developed a strong salt-hunger or calcium hunger.[13]

If this statement seems unusual or paradoxical the reader may be assured that this is only one among many such paradoxes that will appear as we revise our ways of looking at man's deeper motivations. When we ask what man wants of life, we deal with his very essence.

IV. SUMMARY

(1) There are at least five sets of goals, which we may call basic needs. These are briefly physiological, safety, love, 'esteem, and self-actualization. In addition, we are motivated by the desire to achieve or maintain the various conditions upon which these basic satisfactions rest and by certain more intellectual desires.

(2) These basic goals are related to each other, being arranged in a hierarchy of prepotency. This means that the most prepotent goal will monopolize consciousness and will tend of itself to organize the recruitment of the various capacities of the organism. The less prepotent needs are [p. 395] minimized, even forgotten or denied. But when a need is fairly well satisfied, the next prepotent ('higher') need emerges, in turn to dominate the conscious life and to serve as the center of organization of behavior, since gratified needs are not active motivators.

Thus man is a perpetually wanting animal. Ordinarily the satisfaction of these wants is not altogether mutually exclusive, but only tends to be. The average member of our society is most often partially satisfied and partially unsatisfied in all of his wants. The hierarchy principle is usually empirically observed in terms of increasing percentages of non-satisfaction as we go up the hierarchy. Reversals of the average order of the hierarchy are sometimes observed. Also it has been observed that an individual may permanently lose the higher wants in the hierarchy under special conditions. There are not only ordinarily multiple motivations for usual behavior, but in addition many determinants other than motives.

(3) Any thwarting or possibility of thwarting of these basic human goals, or danger to the defenses which protect them, or to the conditions upon which they rest, is considered to be a psychological threat. With a few exceptions, all psychopathology may be partially traced to such threats. A basically thwarted man may actually be defined as a 'sick' man, if we wish.

(4) It is such basic threats which bring about the general emergency reactions.

(5) Certain other basic problems have not been dealt with because of limitations of space. Among these are (*a*) the problem of values in any definitive motivation theory, (*b*) the relation between appetites, desires, needs and what is 'good' for the organism, (*c*) the etiology of the basic needs and their possible derivation in early childhood, (*d*) redefinition of motivational concepts, *i. e.*, drive, desire, wish, need, goal, (*e*) implication of our theory for hedonistic theory, (*f*) the nature of the uncompleted act, of success and failure, and of aspiration-level, (*g*) the role of

association, habit and conditioning, (*h*) relation to the [p. 396] theory of inter-personal relations, (*i*) implications for psychotherapy, (*j*) implication for theory of society, (k) the theory of selfishness, (*l*) the relation between needs and cultural patterns, (*m*) the relation between this theory and Alport's theory of functional autonomy. These as well as certain other less important questions must be considered as motivation theory attempts to become definitive.

Notes

[1] As the child grows up, sheer knowledge and familiarity as well as better motor development make these 'dangers' less and less dangerous and more and more manageable. Throughout life it may be said that one of the main conative functions of education is this neutralizing of apparent dangers through knowledge, *e. g*., I am not afraid of thunder because I know something about it.

[2] A 'test battery' for safety might be confronting the child with a small exploding firecracker, or with a bewhiskered face; having the mother leave the room, putting him upon a high ladder, a hypodermic injection, having a mouse crawl up to him, etc. Of course I cannot seriously recommend the deliberate use of such 'tests' for they might very well harm the child being tested. But these and similar situations come up by the score in the child's ordinary day-to-day living and may be observed. There is no reason why those stimuli should not be used with, far example, young chimpanzees.

[3] Not all neurotic individuals feel unsafe. Neurosis may have at its core a thwarting of the affection and esteem needs in a person who is generally safe.

[4] For further details see (12) and (16, Chap. 5).

[5] Whether or not this particular desire is universal we do not know. The crucial question, especially important today, is "Will men who are enslaved and dominated inevitably feel dissatisfied and rebellious?" We may assume on the basis of commonly known clinical data that a man who has known true freedom (not paid for by giving up safety and security but rather built on the basis of adequate safety and security) will not willingly or easily allow his freedom to be taken away from him. But we do not know that this is true for the person born into slavery. The events of the next decade should give us our answer. See discussion of this problem in (5).

[6] Perhaps the desire for prestige and respect from others is subsidiary to the desire for self-esteem or confidence in oneself. Observation of children seems to indicate that this is so, but clinical data give no clear support for such a conclusion.

[7] For more extensive discussion of normal self-esteem, as well as for reports of various researches, see (11).

[8] Clearly creative behavior, like painting, is like any other behavior in having multiple, determinants. It may be seen in 'innately creative' people whether they are satisfied or not, happy or unhappy, hungry or sated. Also it is clear that creative activity may be compensatory,

ameliorative or purely economic. It is my impression (as yet unconfirmed) that it is possible to distinguish the artistic and intellectual products of basically satisfied people from those of basically unsatisfied people by inspection alone. In any case, here too we must distinguish, in a dynamic fashion, the overt behavior itself from its various motivations or purposes.

[9] I am aware that many psychologists md psychoanalysts use the term 'motivated' and 'determined' synonymously, *e. g*., Freud. But I consider this an obfuscating usage. Sharp distinctions are necessary for clarity of thought, and precision in experimentation.

[10] To be discussed fully in a subsequent publication.

[11] The interested reader is referred to the very excellent discussion of this point in Murray's *Explorations in Personality* (15).

[12] Note that acceptance of this theory necessitates basic revision of the Freudian theory.

[13] If we were to use the word 'sick' in this way, we should then also have to face squarely the relations of man to his society. One clear implication of our definition would be that (1) since a man is to be called sick who is basically thwarted, and (2) since such basic thwarting is made possible ultimately only by forces outside the individual, then (3) sickness in the individual must come ultimately from sickness in the society. The 'good' or healthy society would then be defined as one that permitted man's highest purposes to emerge by satisfying all his prepotent basic needs.

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