LANDFARM DESIGN AND MANAGEMENT IN BOLIVIA: A CASE-STUDY

Walter Younkin, Cecilia Suaznábar, Shannon Parsons, Eduardo Avila
Concordia Environmental Services, Inc., Empresa Petrolera CHACO S.A., Parsons Environmental Corp., Empresa Petrolera CHACO S.A.

Abstract

A liability audit of Empresa Petrolera CHACO, S. A. (CHACO), identified about 55,000 m^3 of TPH (Total Petroleum Hydrocarbon) contaminated soils from prior operations. New operations also required a cost effective approach to oily wastes disposal. Sites are remote, with various climates and limited availability of equipment. Landfarming, used in North America was identified as the most cost effective method for remediating these wastes.

Since no landfarming regulations existed in Bolivia, guidelines were taken from Canada and the U.S. The first site, in Los Cusis, was located in a subtropical humid region north of Bolivia. Heavy rains and a shallow ground water table required careful planning, and monitoring of soils and ground water. Results showed reductions of TPH from highs of 15% in applied wastes, to less than 1% in treated soils within seven months. Monitoring confirmed that landfarming had no impact on shallow groundwater. Other landfarms in operation are; Camatindi, located in the mountains in southern Bolivia and Patujusal, located close to the Los Cusis area.

Land farming has been successful for CHACO, due to careful design, proper management, and reliable sampling and analysis. This paper provides a summary of results from Los Cusis and design parameters from Camatindi.

Introduction

In December of 1996 Amoco Corporation (now BP) was selected as the strategic partner in a new Bolivian oil and gas company. CHACO, was formed from the capitalization of the Bolivian state oil company Yacimientos Petroliferos Fiscales Bolivianos (YPFB). Under the capitalization process, an environmental liability assessment of the properties and assets was required within the first year of operation. All environmental liabilities were to be identified and assessed to define remediation requirements. The waste management component of this 1997 site assessment, identified approximately 55,000 m^3 of hydrocarbon contaminated soils and wastes from widely scattered and, in some cases, remote sites. Remediation costs (US dollars) were estimated to range from $7.5 to $11 million, however the Bolivian government had only set aside $3.6 million. Although the assessment report indemnified CHACO from liability for past contamination, CHACO's objective was to select clean up options and manage remediation efforts to clean up as much of the contamination as possible within the $3.6 million allocated.

Several remediation methods were examined for cost-effectiveness and practicality given the relatively remote conditions and limited resources available. These included landfill disposal, soil washing, burning and other in-situ treatment methods. In the final analysis, landfarming was chosen as the preferred and most cost effective method for remediation of these materials. As well, landfarms could be used for the disposal of oil based drill cuttings from ongoing drilling operations. CHACO's experience in developing and operating cost effective landfarm operations in Bolivia, is described in this paper.

Three landfarms have been constructed to date: the first in the subtropical area north of Santa Cruz (Los Cusis Landfarm); a second in the southern mountains near the community of Villamontes (Camatindi Landfarm) and a third in the same region as the Los Cusis landfarm (Patujusal landfarm). All three have been in active operation; however, the Los Cusis landfarm has provided the most data and will be described in detail in this report. In addition, because of its unique position on the slopes of the Aguarague Mountains, the design of the Camatindi Landfarm is briefly described.

Landfarm Concept

The land treatment[1] of non-hazardous oilfield waste is a well recognized and accepted waste treatment and disposal method whereby controlled applications of wastes are made to a dedicated parcel of land (landfarm). The landfarm is managed to assist the inherent ability of the soil system to degrade, transform and assimilate the oily wastes while protecting human health and the environment. Biodegradetion takes place using bacteria that are naturally occurring in the upper soil zones of most ecosystems. Effective treatment is accomplished by optimizing conditions (moisture, oxygen, pH and temperature) that stimulate the growth of these bacteria. To assist biodegradation, land treatment normally includes tillage of the soils for aeration and the application of nutrients. In some cases organic matter can be added to improve aeration and in dry situations, irrigation may be needed. Sampling and analysis are necessary to monitor the progress of biodegradation and for soil and groundwater quality monitoring.

Bolivian Regulatory Requirements

Land treatment of oily wastes is a new concept in Bolivia and the CHACO Landfarms are the first such facilities to be developed. To date few regulations have been established specific to landfarming operations. Regulations[1] applicable to oily wastes disposal require that the wastes must be properly disposed of, but are flexible regarding the method of disposal. Article 34 of the Hydrocarbon Sector

Environmental Regulations indicates that for the treatment of soils contaminated with hydrocarbons or chemical products, the operator must provide (1) a detailed characterization of the wastes to identify its components and its compatibility with the treatment of the soil, (2) the selection of the site to identify its compatibility and the capacity of the terrain for the treatment, (3) determination of the level of pollutants to be added to the soils, (4) evaluation of the risks to public health and the environment, and (5) monitoring reports to describe the results of activities.

To provide more comprehensive guidance concerning environmental soil and water standards, CHACO also applied various international guidelines from regulatory agencies and authorities in the United States and Canada. Refs. 2 through 5 address criteria applied to soil and groundwater monitoring.

Site Selection and Design

A review of the oily waste inventories identified in the 1997 site assessment and an evaluation of logistic requirements, including haul distances from cleanup/drilling operations, formed the basis for identifying potential landfarm sites. Key environmental considerations included proximity to communities, and the potential for surface or ground water contamination.

Land farm facility layouts, operating procedures and soil and water monitoring criteria published by industry, regulatory agencies and experts in the United States and Canada, were consulted to prepare landfarm designs and management guidelines. Refs. 2 through 9 address land treatment facilities and waste applications requirements. Varying climatic conditions and topography in CHACO's areas of operation were important factors in the design and development of landfarm operations. Heavy seasonal rain, drought and steep topography all played a role in design and construction.

Design/setup features common to all sites included: fencing to restrict access, signs informing the public the nature of the facility, access roads and gates, perimeter berms to control movement of water on and off the treatment areas, oil traps at surface water exit sites, soil baseline assessment, and soil and groundwater monitoring programs. In areas of heavy seasonal rains, it was important to have the landfarm contoured and bermed to control and direct landfarm runoff through the oil traps. On drier sites, the same berms were closed and used to keep moisture on the site. In this case, oil traps are not necessary. On steeper sloped sites such as the Camatindi Landfarm, interception ditches, berms and additional erosion controls were required.

Landfarm Operations and Management

Clearly stated operating practices are important to ensure consistent and cost effective treatment. CHACO's landfarm management strategies were developed from typical industry practices and compiled into a comprhensive facility operations manual. This manual includes guidance to the manager, gatekeeper and monitors, and provides information and forms for topics ranging from cell loading to sample collection and handling. The following outlines some of the key landfarm management practices in use at CHACO's landfarm facilities.

Security and Access. A gatekeeper, who is responsibile for scheduling and receiving all wastes for treatment, controls access to the landfarm. The gatekeeper also maintains a log of waste inventories and facility operations including waste application, treatments and monitoring programs.

Application Criteria and Loading Limits. Wastes are analyzed and a waste profile submitted prior to treatment of any waste at the facility. Constituents with the potential of limiting plant growth or future land use are assessed based on analysis of the waste and baseline soils and by comparison with Maximum Soil Application Values (MSAV). MSAV are established for soil salinity and metals to assess waste loading levels. These values were derived from the State of Louisiana Department of Natural Resources (DNR)[3,5] as they apply to the treatment and disposal of nonhazardous exploration and production wastes. This comparison identifies any land-limiting constituent and dictates waste specific application rates to assure successful land treatment while protecting future land use. Soil samples for measurement of treatment performance (pH, EC, nutrients, TPH) are collected prior to the initial application of waste or any reapplication in active treatment areas. The TPH objective for completed treatment is set at 1% based on studies that demonstrate that 1% hydrocarbon by weight is the threshold for the initiation of reductions for some sensitive crops.[6, 7,8]

Environmental Monitoring. Soil and groundwater baselines are established prior to waste applications. These provide a basis for monitoring programs that assess performance, effects on the surrounding groundwater and soil, and establish the acceptable frequency for waste application and maintenance activities. With this information adjustments can be made in the application of wastes and monitoring programs, improving the efficiency of operation. All samples are collected in accordance with standard procedures and forwarded to an accredited laboratory for analysis.

Record Keeping. Records are kept of all waste chemical analysis, soil application, amendments (date, type, rate, coded area), cultivation treatments (date, equipment used, depth penetration, soil moisture conditions) and soils/groundwater monitoring. Periodic reports provide a summary of waste received, waste applications, soil amendments and treatments and monitoring programs. These reports also include an assessment of land treatment success and any changes in soil background values or groundwater quality.

Landfarm Sites and Set Up**Los Cusis Landfarm.** The site chosen for the first landfarm was located near the Los Cusis oilfield approximately 70 km north of Santa Cruz. The area lies in the subtropical humid forest region that has an annual precipitation of 1250 to 1450 mm. The surrounding area is generally low and poorly drained with extensive flooding during the summer months. Mean annual temperatures vary from 23 to 25 degrees centigrade.

The Los Cusis Landfarm (**Fig. 1**) is situated on an elevated tract of land of approximately 4 ha. It is surrounded by lowland areas and is distant from any settlements or major watercourses. The site's topography is gently sloping (5%).

To prevent surrounding drainage from moving onto the landfarm a low berm constructed of native clay was pushed up around the site perimeter. Land contouring of the treatment area was used to direct surface drainage into a natural drainage course, which is then channeled through a baffled oil trap that prevents oily water from leaving the landfarm. To facilitate the placement and monitoring of wastes, the landfarm was laid out in a rectangular grid consisting of 9 blocks, further divided into cells of approximately 30 m by 30 m . Each block/cell is numbered and a sign-posted (on the perimeter fence) for record keeping. A covered storage area is located on site for temporary waste storage.

The soils in the upper 60 cm of the landfarm are moderately dense sandy silt with approximately 15 % clay. The clay percentage is high enough to reduce the potential for leaching, yet low enough to reduce hardpan formation and ponding. Underlying these soils is a layer of relatively impermeable clay (70% to >90% clay) generally extending beyond 3.0 meters. A baseline soil survey for detailed salinity and metals was run for future comparisons and monitoring of waste applications. The first groundwater interval is at 1.5 to 1.8 meters. It is confined within the clay rich interval (perched) and not a source of potable water. Four groundwater wells were installed in this groundwater interval for monitoring purposes.

Camatindi Landfarm. The Camatindi landfarm is located in the southern part of the country, in the front range of the Aguarague Mountains at an elevation of 1,614 meters. Precipitation in this area ranges from 900 to 1200 mm per annum. Vegetation cover is primarily grass and the soils that have developed are organic rich loams with depths of up to 1 meter, where bedrock is within 3 meters.

The Camatindi landfarm was established to dispose of oily wastes from a nearby exploration well. The landfarm (**Fig. 2**) is divided into five separate areas that total 1.7 ha. The topography is steep with slope angles ranging from 15 to 25%. The design and operation of a landfarm under such conditions presents some unique challenges related to drainage and erosion control. On steeper slopes, a series of interception ditches and berms are used to direct surface water away from and off the treatment area. Grassed areas (strips) are also used to retard the flow of surface water and prevent erosion within the treatment areas. Because of the potential for periods of heavy rainfall, it is important that all erosion control features are monitored daily to ensure proper performance.

Land Treatment Results

Waste Profile. The first wastes applied to the Los Cusis Landfarm were oil based drill cuttings from active drilling operations in the area. Similar in composition to the wastes to be cleaned up from old abandoned pits, it provided a good opportunity to test the effectiveness of the landfarming approach prior to launching the full-scale field remediation program.

Analysis of typical Los Cusis drill cutting wastes (**Table 1**) show that on average they contained approximately 15% TPH. Metal and salt concentrations are low and do not present any limiting constituents[3,5,6] (excessive parameter concentrations) for waste loading levels in soils. Calculated TPH loading rates for these oil-based drill cutting wastes suggest that a 100 m^3 of 15% TPH waste added to a 1 ha treatment area would yield a TPH of 0.83 % in the 0-15 cm soil mixture. Actual loadings and TPH data indicate that this figure ranges from 0.60 to 1.00 %.

Waste Loadings. Wastes are typically applied in layers of no more than 20 cm and in the case of the Los Cusis Landfarm applications were varied to provide a range of TPH loadings. After receiving waste application, treatment areas are tilled to incorporate the wastes and increase aeration. Tilling frequency is at approximately two-week intervals. A single application of blended fertilizer (15-15-15) to increase nutrient levels was applied to each of the landfarms at a rate of 220 kg/ha. No other treatment or soil amendments were applied.

The landfarm at Los Cusis began operations in April 1998. Over the next 7 months the landfarm received 1751 m^3 of wastes. Waste application rates for Blocks 1, 2, 3, and 6 ranged from 935 m^3/ha on Block 2 to 238 m^3/ha on Block 1 (**Fig. 1 and Table 2**). During this first application phase almost all of the wastes received were from drilling operations. However, during a subsequent application phase the Los Cusis site received 3,600 m^3 of pit sludge associated with the clean up of the Los Cusis field.

TPH Remediation. To assess land treatment performance following the completion of waste loadings, permanent soil sample sites are sampled monthly and analyzed for pH, EC, TPH and moisture content.

Los Cusis TPH Reduction. After incorporation of the 15% TPH drill cuttings at varied rates, initial TPH levels in the 0-15 cm soil-waste mixtures ranged from a high of 5.62 % in Block 2 to a low of 1.49 % in Block 6 (Table 3). These values are based on the first sample analysis performed following the final waste application. Because wastes were applied to most treatment blocks over a 4 to 5 week period these inital TPH values are considered conservative, as some degradation had already occurred prior to sampling. Rates of TPH degradations for the individual treatment blocks are shown in **Figures 3, 4, 5 and 6** and summarized in **Table 3**.

The average number of days to reach the target TPH threshold of 1% for Blocks 1, 2 and 3, ranged from 218 days for Block 2 (initially 5.62%) to 139 days for Block 1 (initially 2.89%). Regardless of the starting TPH the average rate of TPH degradation for these three blocks is 52 days per unit (1%) TPH change. The considerably slower degradation rate of 132 days for Block 6 is attributed to the effects of low soil moisture, as this Block experienced unusual drought conditions for 6 months after initial waste applications.

Monitoring and Assessment.

Soils. In addition to treatment performance monitoring (pH, EC, TPH and moisture), more detailed soil quality monitoring is conducted prior to the initial application of waste or any reapplication in active treatment areas. During this sampling phase a more complete analysis is run and includes: major ions, SAR, CEC, ESP, metals, nutrients and other specific parameters. The average soil salinity and metals results for the Los Cusis Landfarm Blocks 1, 2, 3 and 6 following the first cycle of waste application and treatment, is shown in **Table 4**.

Soil salinity, as measured by Sodium Absorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP), is typically low compared to the MSAV, and reflects the low sodic and saline properties of the applied waste. Current levels do not require salt management or additional amendments.

Reported metals have been incorporate in the treatment zone at concentrations well below the maximum thresholds (MSAV). Increases in metal concentrations are generally small by comparison to baseline values, with the exception of barium. Higher levels of barium reflect additions of insoluble barite ($BaS0_4$) used as an additive in drilling mud to increase mud weight. Barium sulfate is the lower toxicity form of barium salts, thus the high MSAV (100,000 ppm) developed under the State of Louisiana DNR[2]. Based on soils monitoring, the only limiting factor that could impact future waste application rates to active treatment blocks, is the waste concentrations of barium (barite).

Groundwater. Groundwater quality for the Los Cusis Landfarm is monitored routinely for pH, Electrical Conductivity (EC) and TPH. More detailed assessment including additional salinity and metals profiles are evaluated quarterly. Monitoring results are summarized in **Table 5**. Although the comparison to potable water guidelines[3] is made for evaluating concentration levels, the shallow groundwater regime underlying the landfarm is not considered a potable water source. This near surface groundwater is primarily perched surface water opposed to a groundwater aquifer and would not meet water quality objectives for human consumption. Groundwater monitoring results for Los Cusis Landfarm have historically shown little change in ionic composition. Any fluctuations have been associated primarily with the groundwater recharge cycles and precipitation events. All reported parameter concentrations are well within potable water standards. TPH and aromatic hydrocarbons are consistently less than the analytical detection limits. To date there has been no evidence that any applied waste components have impacted the shallow groundwater regime underlying the site

Surface Water. The Los Cusis monitoring program also includes monitoring of discharge surface water samples from the oil trap. However, to date no discharge has occurred.

Cost Assessment

One of the primary objectives of CHACO's landfarm operations was to set up and operate these facilities in a cost-effective manner. This required the development of landfarms at the lowest possible cost while protecting human health and the environment and abiding by local and international guidelines. Because costs and suppliers will vary from region to region, detailed cost information is not that useful. However, an overview of the approach and general costs can provide an appreciation for what the general set up and operational costs can be in situations similar to Bolivia. The following are costs in US dollars from the set up and operation of the Los Cusis Landfarm.

Set Up Costs. As indicated previously, the landfarm set up entails, clearing, fencing, gates, signs, groundwater wells, covered storage area, short access road, land contouring and drainage control, oil traps and baseline soils chemistry assessment. On the basis of the above, our approximate costs for setting up a 4 ha landfarm are in the order of $47,000. This cost includes funds for construction management during the 30 to 40 day period of construction and a 5% contingency.

Operations Costs. Land farm operations costs include fees for a gatekeeper (who controls access and keeps track of loading rates etc.), annual lease of land, bimonthly tilling of land (assumes use of a local farmer), sampling and analysis of soils and ground water, data assessment and monthly operations reports. Operations costs do not include hauling costs as transport distances/costs vary. The location of the landfarm ultimately determines these costs and is an important consideration. Using the above it was determined that monthly operations costs for a 4 ha landfarm are in the order of $6,700.

Waste Treatment Costs. In the Los Cusis Landfarm case, the unit cost to treat 1 m^3 of drill cuttings ranges from $10 to $14. This cost is derived by taking the operations costs, amortizing setup costs over 3 years, a loading rate capacity of 1000 m^3/ha and a 5 to 7 month treatment period to achieve an objective 1% TPH. Obviously the treatment cost per cubic meter of waste will vary depending upon the number of cubic meters that are applied. If wastes are applied at less than the landfarm capacity, then the unit cost will increase proportionately. One of the keys to running an economical landfarm operation is to properly size the operation and manage it so that it is kept at or near capacity.

Conclusions

The following are conclusions drawn from the landfarming of oily wastes at CHACO's Los Cusis Landfarm:

1. The development and operation of CHACO's landfarms demonstrate that with proper design and management, landfarming can provide an effective method of disposing of oily wastes in Bolivia

Using oil based drill cuttings for initial land treatment trials, bacteria naturally present in the Bolivian soil systems was effective in biodegrading hydrocarbon concentrations to acceptable levels.

2. Oil based drill cuttings containing 15% TPH and applied at loadings of 238 to 935 m^3/ha, are reduced to target levels of 1% TPH in the soils within 5 to 7 months. This was accomplished with minimal treatments including tilling (aeration) and fertilizer addition.

3. Land farm TPH biodegradation rates measured in days per unit (1%) change, averaged 52 days for completed Los Cusis Landfarm trials. Biodegradation rates during periods of drought are considerably slower, but quickly accelerate following the first rainfall.

4. Monitoring of soil and groundwater quality at the Los Cusis Landfarm found no negative impacts that would affect the surrounding environment or local communities.

5. Based on the Los Cusis Landfarm, set up costs (US dollars) for a 4 ha landfarm are in the order of $47,000 with operational costs of approximately $6,700/month. At a capacity waste-loading rate of 1000 m^3/ha, this translates to a waste treatment cost (excluding waste hauling costs) in the range of $10 to $14/$m^3$.

The findings demonstrate that this treatment process can meet CHACO's remedial program objectives of applying an effective lower cost approach to the disposal and remediation of oily wastes, while providing adequate protection of public health and the environment. The landfarms as developed involve low capital investment and operating costs and with proper management should prove to be efficient operations in the future. Careful and well-managed application of this technology will mean that cleanup of contaminated sites can be achieved economically over a reasonable time frame.

Nomenclature

mg/L = milligrams per liter (ppm)

ug/L = micrograms per liter (ppb)

meq/L = mill equivalents per liter

ug/g = micrograms per gram (ppm)

ha = hectare

m^3 = cubic meters

MSAV = maximum soil application values

TPH = total petroleum hydrocarbons

SAR = sodium adsorption ratio

ESP = exchangeable sodium percentage

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TABLE 1 Los Cusis Landfarm Drill Cuttings Waste Profile Average (n=10)		
Parameters	**Units**	**Conc.**
Hydrocarbons		
TPH dry weight basis)	%	15.4
Moisture	%	13.3
Salinity/Major Ions		
pH	Units	9.70
Conductivity	mmhos/cm	1.6
Calcium	ug/g	18,167
Magnesium	ug/g	3,740
Potassium	ug/g	1,353
Sodium	ug/g	617
Sulfate	ug/g	136
Chloride	ug/g	193
Cation Exchange Capacity	meq/100 g	4.6
Sodium Adsorption Ratio	Units	6.8
Extractable Sodium	meq/100 g	1.4
Exchangeable Sodium	meq/100 g	0.3
Exchangeable Sodium Percentage	%	5.8
Metals		
Arsenic	ug/g	7.8
Barium	ug/g	3,518
Beryllium	ug/g	<0.5
Boron	ug/g	30
Cadmium	ug/g	0.6
Chromium	ug/g	14.5
Copper	ug/g	150
Lead	ug/g	44
Mercury	ug/g	0.4
Nickel	ug/g	8.1
Selenium	ug/g	1.5
Silver	ug/g	<0.5
Vanadium	ug/g	8.0
Zinc	ug/g	87

TABLE 2 Los Cusis Landfarm 1st Waste Application Cycle			
	Block #	**OBCTotal (m^3)**	**Rate (m^3/ha)**
	1	129	238
	2	493	935
	3	236	437
	6	219	756
Total		1,278	

OBC – Oil based drill cuttings
n – Number of samples

TABLE 3
Los Cusis Landfarm
TPH Degradation

Block #	Initial Soil Mix Analysis (% TPH dry wt.)	Days To Reach 1% TPH Threshold	Degradation Rate (Days/ Unit (1%) TPH Change)
1	2.89	139	56
2	5.62	218	44
3	4.37	212	57
6	1.49	161	132

TABLE 4
Los Cusis Landfarm
Soil Monitoring At Completion Of 1st Waste Application Cycle

SOIL Depth Blocks 1, 2, 3 and 6		0-15 cm Average n=4	MSAV
Parameters	**Units**	**Conc.**	**Conc.**
Salinity/Major Ions			
pH	Units	7.9	6 to 9
Conductivity	mmhos/cm	0.9	<10
Calcium	meq/L	3.7	NV
Magnesium	meq/L	0.7	NV
Potassium	meq/L	0.4	NV
Sodium	meq/L	4.4	NV
Bicarbonate	meq/L	3.4	NV
Sulfate	meq/L	2.2	NV
Chloride	meq/L	2.7	NV
Cation Exchange Capacity	meq/100g	13.9	NV
Sodium Adsorption Ratio	Units	2.9	<12
Extractable Sodium	meq/100g	0.8	NV
Exchangeable Sodium	meq/100g	0.4	NV
Exchangeable Sodium Percentage	%	2.8	<15
Metals			
Arsenic	ug/g	8	40
Barium	ug/g	6,748	100,000
Beryllium	ug/g	<0.5	NV
Boron	ug/g	37	NV
Cadmium	ug/g	<0.5	10.0
Chromium	ug/g	5	1,000.0
Copper	ug/g	80	NV
Lead	ug/g	26	1,000.0
Mercury	ug/g	0.5	10.0
Nickel	ug/g	9	NV
Selenium	ug/g	<1.5	10.0
Silver	ug/g	<0.5	200.0
Vanadium	ug/g	9	NV
Zinc	ug/g	32	500.0

MSAV – Maximum Soil Application Values
Source: References 3, 5 and 6

TABLE 5
Los Cusis Landfarm
Groundwater Monitoring

Sample Period LCS Wells 1-4 Samples		Jan/00 Average n=4	MOEE Potable Water Standards
Parameters	**Units**	**Conc.**	**Conc.**
Hydrocarbons			
TPH	mg/l	<1.0	1
Benzene	mg/l	<0.001	0.005
Toluene	mg/l	<0.001	0.024
Ethyl Benzene	mg/l	<0.001	0.002
Xylenes (total)	mg/l	<0.001	0.300
Salinity/Major Ions			
pH	units	6.50	NV
Conductivity	umhos/cm	490	NV
Sodium	mg/l	44	200
Potassium	mg/l	7	NV
Calcium	mg/l	65	NV
Magnesium	mg/l	11	NV
Sulfate	mg/l	41	NV
Chloride	mg/l	96	250
Metals			
Arsenic	mg/l	<0.01	0.025
Barium	mg/l	0.58	1
Beryllium	mg/l	<0.005	0.004
Boron	mg/l	<0.15	5
Cadmium	mg/l	<0.005	0.005
Chromium	mg/l	<0.01	0.05
Copper	mg/l	0.01	0.023
Lead	mg/l	<0.01	0.01
Mercury	mg/l	<0.0005	0.0001
Nickel	mg/l	<0.02	0.1
Selenium	mg/l	<0.015	0.01
Silver	mg/l	<0.005	0.001
Vanadium	mg/l	<0.01	0.2
Zinc	mg/l	0.07	1.1

MOEE – Ontario Ministry of Environment and Energy
Source: Reference

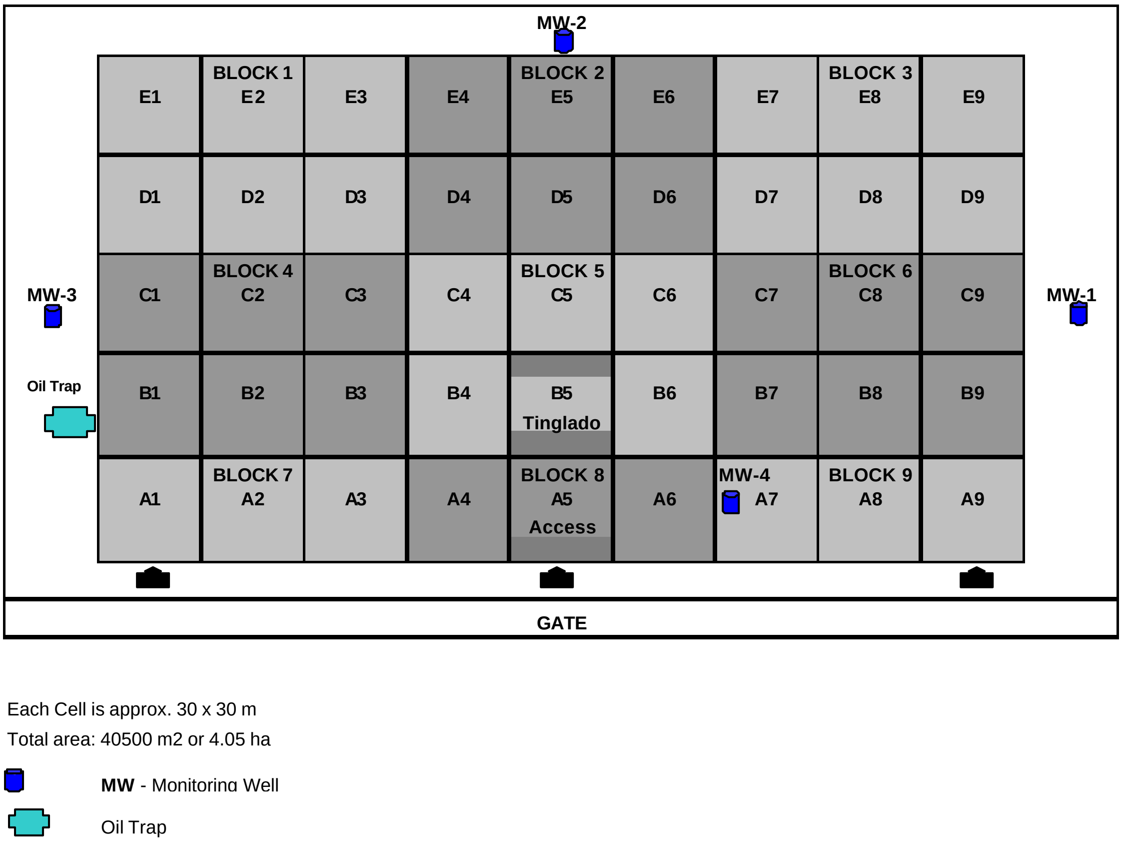
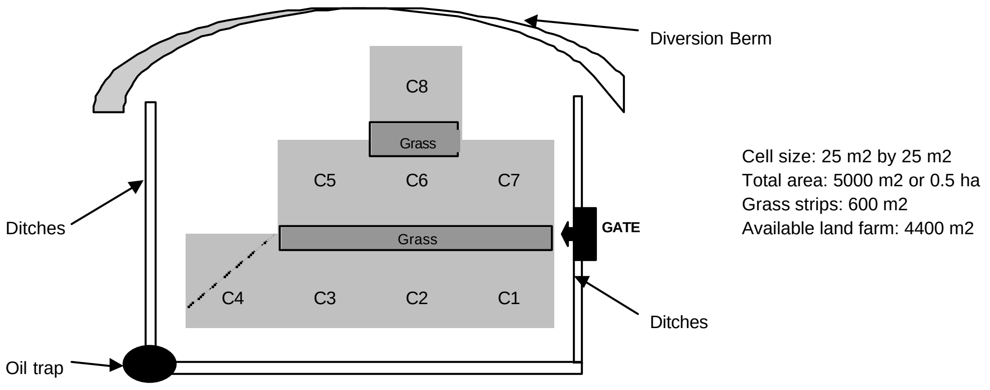
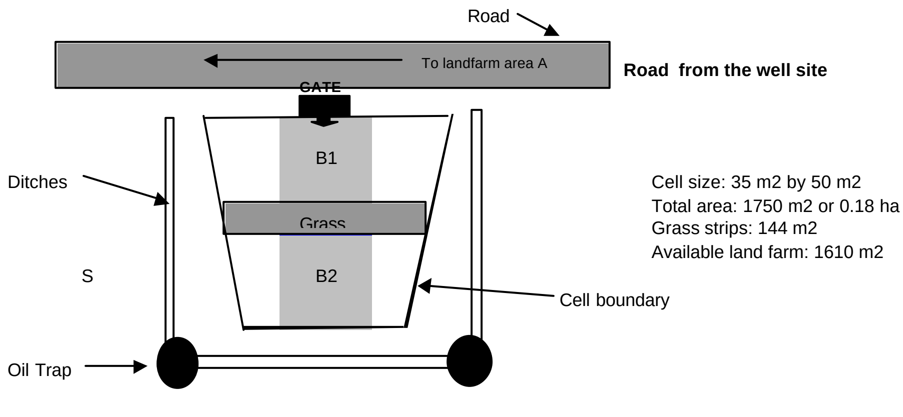


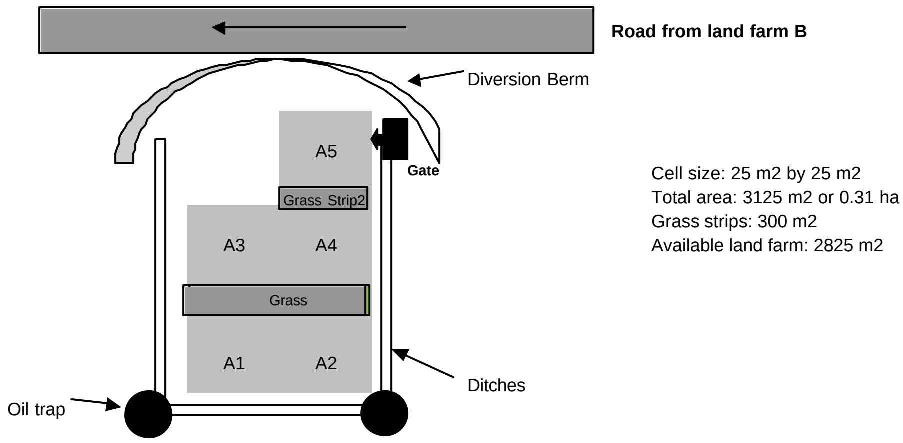
Fig. 1- Los Cusis Landfarm, Plan View



Land Farm Area C



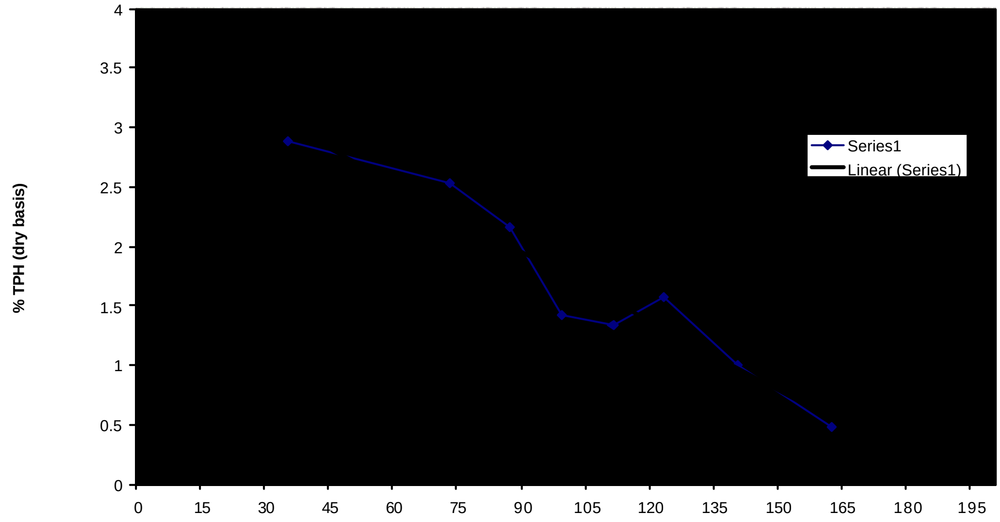
Land Farm Area B



Land Farm Area A

TOTAL LAND FARM
Total area: 9875 m2 or 0.99 ha
Grass strips: 1040 m2
Available landfarm: 8835 m2

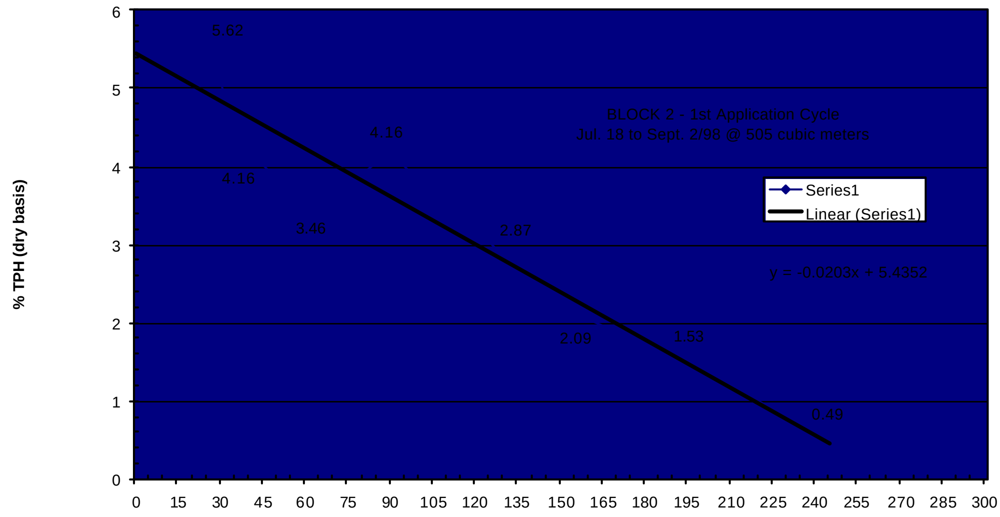
Fig. 2- Camatindi Landfarm, Plan View



	0	35	73	87	99	111	123	140	162
Series1		2.89	2.53	2.17	1.43	1.34	1.57	1.01	0.48

Treatment Period (days)

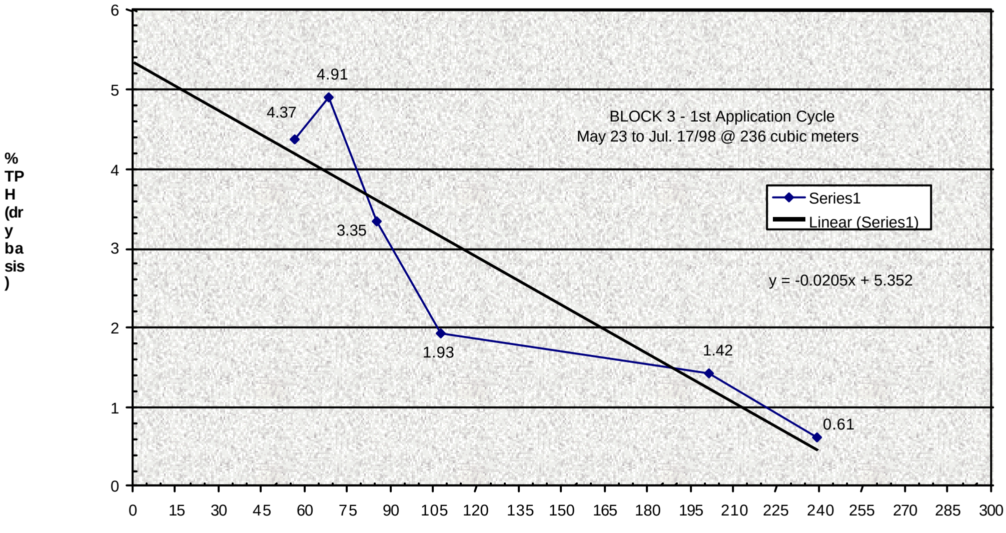
Fig. 3- Los Cusis Landfarm Block 1, 1st Waste Application Cycle TPH Monitoring of 0-15 cm Soils



	0	23	40	62	90	130	156	194	245
Series1		5.62	4.16	3.46	4.16	2.87	2.09	1.53	0.49

Treatment Period (days)

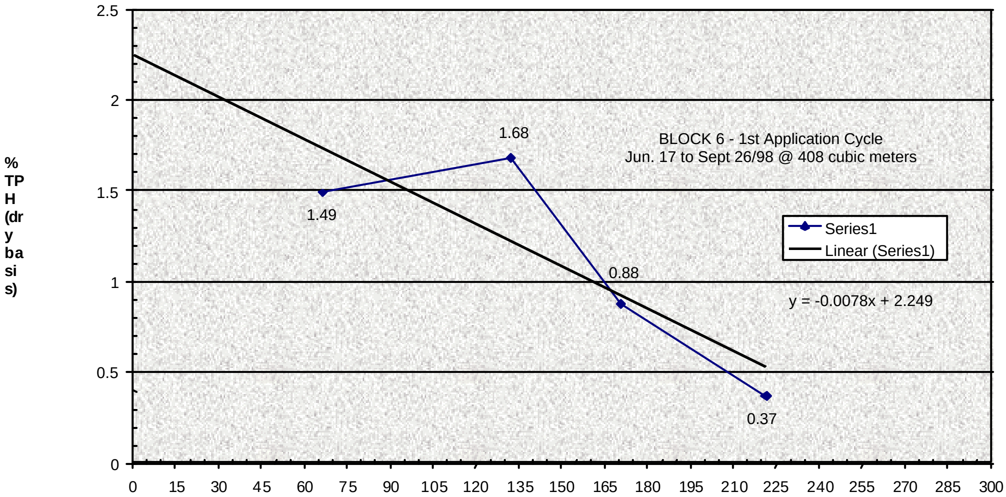
Fig. 4- Los Cusis Landfarm Block 2, 1st Waste Application Cycle TPH Monitoring of 0-15 cm Soils



	0	56	68	85	107	201	239
Series1		4.37	4.91	3.35	1.93	1.42	0.61

Treatment Period (days)

Fig. 5 - Los Cusis Landfarm Block 3, 1st Waste Application Cycle TPH Monitoring of 0-15 cm Soils



	0	66	132	170	221
Series1		1.49	1.68	0.88	0.37

Treatment Period (days)

Fig. 6- Los Cusis Landfarm Block 6, 1st Waste Application Cycle TPH Monitoring of 0-15 cm Soil