

RESEARCH

The OSSA II Pipeline Oil Spill: The Distribution of Oil, Cleanup Criteria, and Cleanup Operations

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An estimated 29,000 bbl of mixed crude oil and condensate were spilled on 30 January 2000 from the OSSA II pipeline, which was damaged during summer flood conditions, at the Río Desaguadero river crossing on the Bolivian Altiplano. The oil was deposited as far as 370 km downstream along a total of approximately 400 km of river channel banks, meander flood plains, and irrigation ditches, as well as on several hundred hectares of low-lying flood plain wetlands. The oil was transported over a large geographic area but was cleaned up successfully and rapidly, in three months, by a large response operation that involved more than 3600 people, including 3200 local laborers at the peak period, using manual cleanup methods. Second phase cleanup activities after April 2000 focused on oiled vegetation and on man-made canals, ditches and livestock watering holes. Four sets of cleanup end points were used during this response to address specific environmental conditions: the reopening of the Desaguadero river for normal use; the removal of the oil residues; oiled vegetation used as forage; and man-made canals, ditches and watering holes. An inspection and documentation procedure was developed based on systematic aerial videotape surveys to assist operations with the removal of the oil residues and to ensure that cleanup standards were met.

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Introduction

The OSSA II pipeline runs from Cochabamba, Bolivia, over the Eastern Cordillera of the Andes, where it reaches an elevation of 4500 m, across the Altiplano, to Arica on the Pacific coast of Chile. The oil spill of 30 January 2000 occurred at the Río De-

saguadero crossing point at an altitude of approximately 3700 m and affected the adjacent closed basin system. The Río Desaguadero flows southwards and connects Lago Titicaca with Lago Uru Uru and Lago Poopó (Fig. 1) and the river basin is a high-altitude desert. The timing of the spill coincided with bank-full flood conditions and the highest water levels of the rainy season.

An estimated 29,000 bbl of mixed crude oil and condensate were spilled and the chemical character and weathering of the spilled oil are described by Douglas *et al.* (2002), Lee *et al.* (2002), and Owens *et al.* (2001). A containment and recovery response

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Fig. 1 Location of the spill site.

was initiated immediately and the affected area was divided into six operational zones (Fig. 2). A cleanup program using local labor was organized that peaked at a total of 3200 in March and details on the cleanup activities are provided in a series of internal project reports (e.g., Polaris, 2000a,b; Transredes, 2001). Extensive sampling was conducted to determine the risk from the oil residues and to monitor water and sediment quality throughout the affected area (Taylor *et al.*, in preparation). The majority of the cleanup was completed by the end of April 2000, but a second phase cleanup program to remove oiled vegetation was carried out through the winter months in Zone 6 to address perceived impacts to forage and grazing animals.

A team of agronomists, veterinarians, and medics was established to deal with the social and human-use

issues and a comprehensive damage assessment study was conducted as part of the compensation program. The results of these activities and a description of the agreements reached with the communities involved are described by Henshaw *et al.* (2001).

This discussion focuses on three topics: (a) a description of the assessment techniques that were developed to locate and describe the oil, (b) the cleanup criteria and cleanup endpoints that were used to guide the operations, and (c) the cleanup techniques that were used to remove the spilled oil.

The Climate of the Region

The region is a high-altitude desert environment with elevations on the order of 3750 m (12,500 ft) and

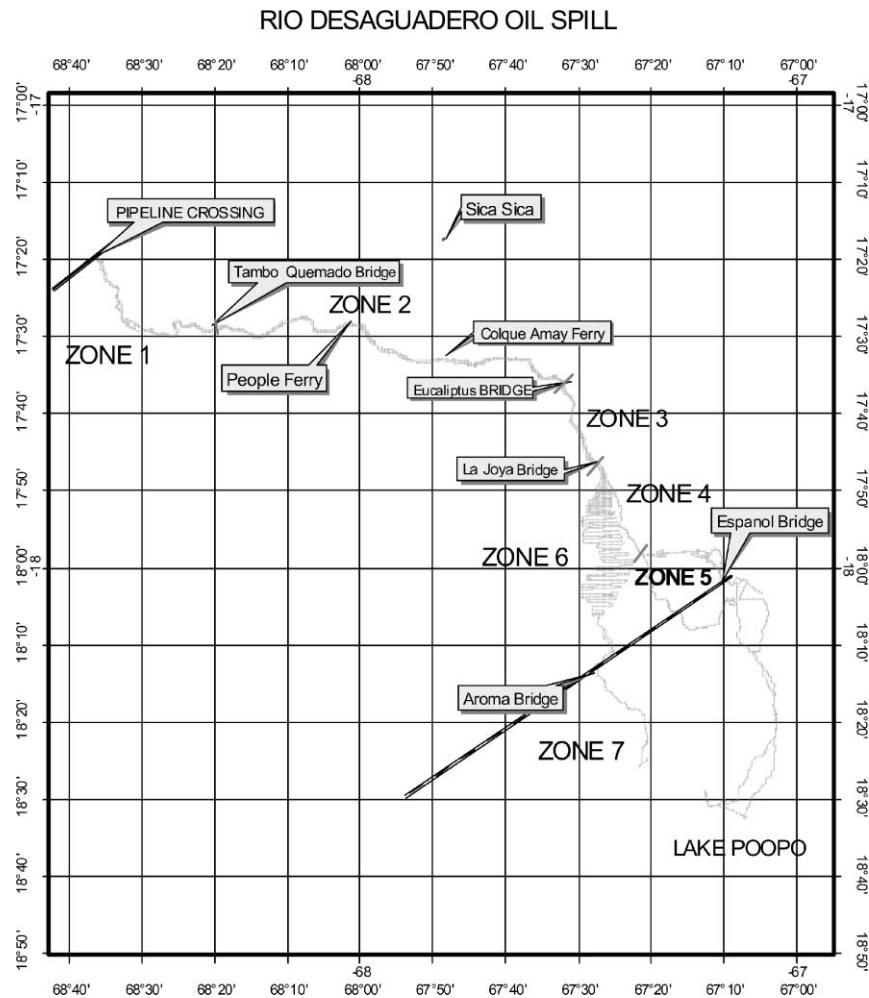


Fig. 2 Operational zones in the affected area. The line southwest from the Espanol Bridge is an embankment with a road that marks the southern boundaries of Zones 5 and 6: the flood waters are channeled through culverts during the rainy season.

a 25-year (1975–1999) average total annual precipitation of 416 mm. There is considerable variation in the annual precipitation with a range of values from a low of 206 mm (1991) to a high of 762 mm (1985). The distribution is highly seasonal with the majority of the annual total occurring in December to March and frequently there is no precipitation during winter months (June and July) (Table 1). Air temperatures during summer months usually are between 5 and 10 °C at night rising up to 20 °C in the afternoons. In winter months, the dry season, the night temperatures frequently fall to –10 or –5 °C, with day-time highs reaching 15–20 °C in direct sunlight (Table 1).

The Río Desaguadero River System

The Río Desaguadero is the primary river that drains the southern central Altiplano of Bolivia. The river originates as the only overflow exit from Lago Titicaca, where the discharge into the Desaguadero is

controlled, and drains approximately 400 km downstream into Lagos Uru Uru and Poopó. The elevation of Lago Titicaca is 3815 m and of Lago Poopó is 3685 m. This is a closed basin system and the waters typically are brackish. Little sediment enters the Desaguadero from Titicaca, but there is a high suspended load input from the Río Mauri tributary which joins the Desaguadero a few kilometers upstream of the spill location (Fig. 1). In exceptionally dry years, such as 1970, the flow reverses towards Lago Titicaca from Río Mauri.

River flow and discharge

Flow rates in the Desaguadero depend on the controlled outflow from Lago Titicaca and on precipitation in the catchment area. The Río Mauri is the primary tributary. Above the confluence with the Río Mauri at Calocoto, a few kilometers above the pipeline crossing (Fig. 1), the annual average flow rate of the Desaguadero is in the order of 50–75 m³ s⁻¹. There

Table 1 Climatic data for Oruro: Lat. 17° 57' S; Long. 66° 59' W (source: SENAMHI Servicio Nacional de Meteorología e Hidrología, La Paz)

Parameter	Unit	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	A-E-T ^a
Precipitation	mm	88.8	65.4	48.7	8.3	3.1	0.0	0.0	6.4	12	14.9	20.9	53.6	T 332.1
Precipitation	Days	13	10	11	5	1	1	0	2	5	5	6	8	T 68
T Max.	°C	22.2	21.8	21.4	20.6	19.2	17.2	17.4	19.5	19.9	22.2	23.2	23.1	E 23.2
T Min.	°C	1.0	1.5	-6	-5.3	-10.8	-12.7	-11.3	-10.7	-7.8	-5.1	-2.7	-1.3	E -13.3
Relative humidity	%	59.3	56.2	57.6	50.4	42	40.3	38.7	37.8	40.7	40.4	42.1	45.6	A 45.9
Wind speed ^b	Knots	E-6	E-6	E-6	E-5	SW-4	S-4	NW-4	S-4	N-5	S-6	S-6	E-7	A SE-5
Frost	Days	0	1	1	12	28	29	30	29	23	11	6	2	T 172
Hail	Days	0	1	1	0	0	0	0	0	0	1	0	0	T 3
Mean temperature	°C	12.9	12.6	12.5	11.7	8.2	5.8	5.7	7.6	10.3	12.7	13.7	13.4	A 10.6
Insolation	h/luz	6.5	7.3	7.3	9.7	10.5	10.9	10.4	10.2	6.7	9.3	9.3	7.4	A 8.8

^a A = Average E = Extreme T = Total.

^b And prevailing wind direction.

is a very strong seasonal input during the rainy season (December–March) from Río Mauri (up to 50 m³ s⁻¹), which drains the uplands of the Western Cordillera. The Mauri provides little input (flow rates < 10 m³ s⁻¹) during the remaining dry season months. Typical flood discharges in the Desaguadero during the period of maximum flow (January–March) are of the order of 120 m³ s⁻¹ (Guyot *et al.*, 1990).

At Inti Raymi, just below Puente La Joya, the measured mean annual flow is on the order of 90 m³ s⁻¹. The flow is highly seasonal and mirrors the precipitation seasons (Table 1 and Fig. 3). During the winter in the driest seasons the flow rates can decrease to less than 4 m³ s⁻¹. At the time of the spill, the river was in a high flow condition, with a measured discharge at Inti Raymi of 740 m³ s⁻¹ (Fig. 3) and flow rates over 1.5 m s⁻¹ (Table 2). Measured discharges at Inti Raymi were less than 20 m³ s⁻¹ before and after the 2000 flood season. By comparison, during January and February 2001 the peak measured discharge was 688 m³ s⁻¹ (Engr. Columba, Inti Raymi mine, pers. comm., April 2001).

Water levels

The river waters flooded the delta plain south of Puente La Joya during February and March, 2000. The water level was measured at the time of the spill to be as much as 150 cm above the early January level (Fig. 4). Water depths varied from place to place in the flooded areas during the time that oil was present on the river waters in February, depending on the local topography, but generally depths were in the range of 10–100 cm over the flood plain.

Water levels also varied though time depending on the river volume, for example, there was a second high river discharge event at the end of February that raised water levels almost to the same level as the late-January flood (Figs. 3 and 4). As the water levels and river volume in the river lowered in April and May, the flood plain progressively dried out, so that by late-May only a few areas in Zone 6 remained flooded.

The physical character of the river

Below the pipeline crossing, the Río Desaguadero follows a single large channel for approximately 300 km (Zones 1–3) (Fig. 2, Table 3). In this section the river is confined to a single, wide, channel within which there are mixed reaches with many braided sections and numerous fine sand point bars, mid-channel islands, and shoals. There are extensive flood plains on the meander bends, but elsewhere the channel has eroding cut banks that range up to several meters in height. In this upper section, variations in the flow conditions lead to flood-related and seasonal

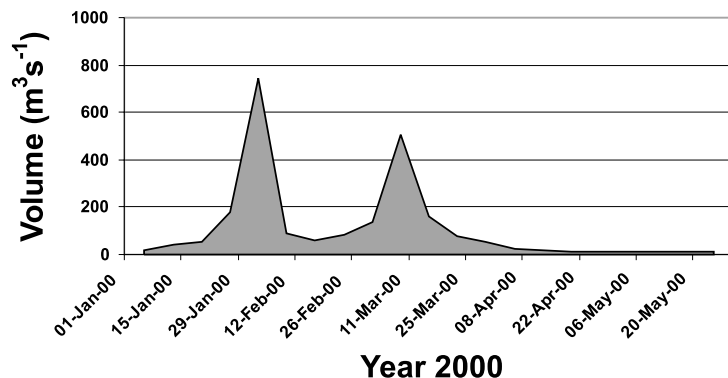


Fig. 3 Discharge of the Río Desaguadero at the Inti Raymi mine, La Joya, January–May, 2000 (see Table 2) (Columba, pers. comm.).

Table 2 Río Desaguadero discharge data (January–May, 2000) at Inti Raymi (source: Columba, pers. comm.)

Date	Area (m ²)	Speed (m s ⁻¹)	Flow volume (m ³ s ⁻¹)
6 Jan	39.45	0.36	18.78
13 Jan	62.95	0.53	42.29
20 Jan	86.18	0.5	53.11
27 Jan	148.6	1	179.95
3 Feb	357.5	1.57	742.16
10 Feb	205.43	0.33	88.15
17 Feb	137.05	0.36	59.97
24 Feb	127	0.54	84.62
2 Mar	168.25	0.62	139.2
9 Mar	226.55	1.87	508.7
16 Mar	269.95	0.44	157.76
23 Mar	119	0.53	77.49
30 Mar	92.35	0.46	53.29
6 Apr	61.05	0.21	25.2
13 Apr	49.5	0.17	16.02
20 Apr	43.15	0.12	11.36
27 Apr	46.05	0.14	12.37
4 May	40.35	0.14	11.3
11 May	37.85	0.12	9.6
18 May	37.03	0.12	9.22
25 May	35.28	0.12	9.53

alternating exposure and inundation of the many bars and shoals, and vegetated flood plains.

From Eucaliptus to Lago Poopó the river has a very low slope (approximately 0.03%) and small accumulations of sediment can have a major influence on local water levels and on the course of the channels. Below the La Joya bridge, the river splits and enters a lowland flood plain. The “west river” (Zone 6; Fig. 2) is the primary flow channel that leads to Lago Poopó and the “east river” (Zones 4 and 5) is a secondary flow channel that leads to Lago Uru Uru, which then also connects to Lago Poopó. These wetlands are flooded during the rainy season, beginning in late December or January, and progressively dry out during the following winter months. Several hundred kilometers of hand-dug irrigation channels and ditches provide water to the rural communities for domestic and agricultural use in the area to the southeast of Eucaliptus and in area of the “east river”. These canals and ditches vary in depth and width from several meters to a few centimeters.

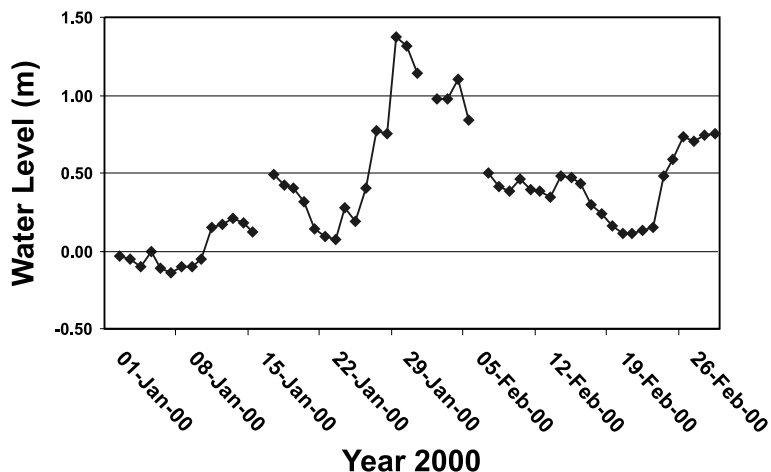


Fig. 4 Measured water levels of the Río Desaguadero at the Inti Raymi mine, La Joya, January–February, 2000 (Columba, pers. comm.).

Table 3 Summary of the physical character of the affected area (based on operational zones—Fig. 2), approximate length of zone, and initial oiling conditions

Zone and length (km)		Physical character	Initial oiling conditions
1	80	Single channel with fine sand point bars and shoals: upland and flood-plain areas	Primarily isolated patches on flood plains: few heavy oiling patches
2A	60	Single, multiple, and braided channels with flood plains, islands, fine sand point bars, and shoals	Primarily isolated patches on flood plains: zone of heaviest oiling following this spill was on the SW bank flood plains
2B	100	Single, multiple, and braided channels with flood plains, islands, fine sand point bars, and shoals	Primarily isolated patches on flood plains: some heavy oiling patches
3	40	Single channel with flood plains, fine sand point bars, and shoals	Primarily isolated patches on flood plains: few heavy oiling patches
4	40	Single channel with flood plains, fine sand point bars, and shoals	Primarily isolated patches on flood plains: few heavy oiling patches
5A	40	Man-modified channel leading to flood plain in SE	Isolated patches on channel margins: scattered over-bank oiling
5B	60	Single small channel, partially man-modified with dykes: with flood plains and fine sand point bars	Very little oil: a few isolated patches on channel margins and occasional over-bank oiling
5C	20	Single small channel, partially man-modified with dykes in lowest reach: with flood plains and point bars	Very little oil: a few isolated patches in lowest reaches
5C - i	>100	Man-made irrigation canals and ditches	Primarily linear (bath-tub ring) stain: some patches of oil on ditch floor
6A	30	Initial confined channels leading to multiple-channel lowland "delta" system with extensive flood plains	Numerous patches on channel margins and extensive over-bank oiling
6B	20	Lowland multiple-channel system with single channel in lowest reach: extensive flood plains	Numerous patches on channel margins and over-bank flood plains
6C	20	Multiple-channel lowland "delta" with extensive flood plains	Numerous patches on channel margins and extensive over-bank oiling
7	60	Single channel leading to extensive delta flood plains	Very little oil: a few isolated patches in uppermost reach
Lago Uru Uru		Shallow Lago with extensive mud flat and wetland shores: multi-channel exit to Lago Poopó	No oil observed
Lago Poopó		Shallow Lago with extensive mud flat and wetland shores	No oil observed

Ecology and wildlife

This high-altitude desert has a sparse vegetation cover of grasses and occasional trees with extensive areas of bare soil or sediment. The soils are primarily loamy and sandy and the surface vegetation includes typical prairie species and in the seasonal wetlands of Zone 6 the vegetation cover is more developed with extensive areas of *totor* reed (*Schenoplectus totora*). The river system supports many species of waterfowl and other birds, including large numbers of flamingo, as well as fish populations. These are not well documented in terms of population numbers and density, however, the Lago Poopó area is considered to be an extremely important area for aquatic birds. The shallow Lago Uru Uru is an important bird reserve as almost all of the 40 known species of aquatic birds of the Altiplano are found in or around the lake (Wasson *et al.*, 2000). Vicuña, the local llama

species, are protected and roam freely throughout the region.

Human activities

The affected region has a rural population of about 30,000 that is dependent on family based subsistence agriculture and animal husbandry, mainly cows and sheep, with smaller numbers of pigs and llamas. The population is primarily Aymaran and Quechuan, with three Uru Muratu communities on the eastern banks of Lago Uru Uru and Lago Poopó. As little as 10% of the population hold land titles and many landowners do not live on the land, but rather rent the land or hire a shepherd who tends his own animals in addition to those of the owner. The farmers depend on the river as a water supply for the cattle, domestic use, and for irrigation.

The Distribution of Oil Residues and the Initial Response

Oil transport

The OSSA II pipeline was carrying a mixture of crude oil and condensate, and an estimated 29,000 bbl spilled directly into the Río Desaguadero over a period of several days at a time of very high discharge. The character and weathering of the spilled oil is described by Douglas *et al.* (2002). Flow velocities were observed in the weeks following the incident to be on the order of 2.5 m s^{-1} or greater. The oil was subjected to high-energy and extremely turbulent flow conditions. The river is shallow, generally less than 3 m deep at flood stage, and the flow was typified by current “boils” and standing waves so that some of the oil was transported downstream on the surface and some would have been entrained (i.e., mixed into the water column) (Owens, 2000). The oil on the water surface was carried down stream rapidly and, at the observed flow rates, some could easily have been transported more than 100 km in one day. An eyewitness report indicates that the oil had reached Toledo, 350 km downstream on the fourth day following the initial release (Wasson *et al.*, 2000).

A primary concern during the initial response was that the oil might affect the Lagos Uru Uru and Poopó. Both lake systems are considered to be of high ecological importance, and both are used by the Uru Muratu peoples for fishing and other subsistence activities. The lakes have been affected by mining activities and domestic run-off for many years and more recently by naturally depleted water volumes.

Initial effects

Wasson *et al.* (2000) reported very few, only on the order of tens, oiled birds in the first days following the spill despite the high bird population in the flooded wetlands. No oiled birds were observed by any of the cleanup crews or other field personnel in the following weeks and months. No other dead wildlife that use the river, particularly the vicuña that graze the river bank areas and drink from the river, were found. The conclusion that the ecological damage from the spill was minimal is based on repeated ground and aerial surveys throughout the entire region during the 12 months following the incident.

The spilled oil was carried downstream under bank-full or flood conditions during the period of the highest rainy-season water levels and was deposited on the meander flood plains in Zones 1–4, and over extensive lowland flood plain wetlands in Zone 6 and parts of Zone 5 (Fig. 2). Little oil reached Zone 7. Oil

was deposited along both banks of a total of approximately 400 km of river channels, meander flood plains, and irrigation ditches, as well as on several hundred hectares of low-lying, delta flood-plain south of La Joya. Some small amounts of oil reached the western shores of Lago Uru Uru, but none reached Lago Poopó. The oil that reached the delta flood plains upstream of the two lakes was filtered as it passed through the wetland vegetation, thus sparing the downstream areas.

The oil also entered the extensive and intricate network of hand-dug canals and ditches that are used to transfer water from the Desaguadero to communities away from the river. The canals were not closed until after the oil had passed the entrances to the primary feeder canals from the river. As a result, several hundred kilometers of the system received oil residues. These residues were weathered oil and were rarely more than a few centimeters in diameter, although several areas in Zone 5 had mats in the order of several meters long, but these were the exception.

The most distant surface oil from the source was located in Zone 7 (near $67^{\circ} 27'30''$ West; $18^{\circ} 14'00''$ South) and in Zone 5C (near $67^{\circ} 11'00''$ West; $18^{\circ} 14'30''$ South), approximately 350 and 370 km downstream respectively (Fig. 2).

No attempt was made to quantify the total surface oil cover as the primary objective of the oil distribution and documentation surveys was to provide the operations team with information on the oil locations for cleanup. Typically, the surface oil cover was scattered with few concentrations greater than 50 m^2 or more than 5 cm thick (Fig. 5). For the most part the surface oil had been deposited in strips, generally 1- or 2-m wide, that were up to 2–3 cm thick. Many sections of riverbank on the main channels and of irrigation ditches had a horizontal line of oil, a thin “bathtub ring”.

The oil was stranded during a range of water levels so that:

- some was well above the range of water levels that were observed during the cleanup program,
- some was being actively washed by the river currents, and
- some was deposited on shoals, covered by river waters, but then re-exposed.

Oil was stranded in a range of water-saturated and dry conditions including:

- silt-fine sand point bars, channel margin, or mid-channel shoals,
- fine-sand point bars, channel margin, or mid-channel shoals,



Fig. 5 Aerial view to the west, from approximately 150 m above the ground, of stranded oil on exposed sand bars in Zone 3 on 25 February, 2000. The main channel of the Desaguadero is in upper frame and during the flood stage the water extended to the vegetated area in the lower right.

- vertical and/or eroding river cut banks,
- vegetated flood-plain areas that initially were wet but later dried out,
- reed (*titora*) habitats, known locally as *totorales*, and
- over-bank vegetated areas (primarily short grasses).

A second high-water level associated with high runoff in early March (Fig. 3) caused some of the stranded oil to be buried by a clean layer of silt.

The vegetation typically had small amounts of weathered oil on the upper stems, as the oiling occurred during the flood period when most of the stems were below water level. As the oil was viscous, it did not flow down the stems to the roots and most of the intervening ground surfaces had no observable oil.

Oil mapping and documentation

An aerial mapping and videotape documentation program was initiated that eventually covered more than 6000 km of river and wetlands in the affected area. The purpose of the program was to locate oil residues and to record that the cleanup operations had been completed successfully to predefined criteria. The surveys were designed to obtain an accurate, detailed, systematic, and complete documentation (Owens & Reimer, 2001; Polaris, 2000a). A set of

“Cleanup Map Categories” was developed (Table 4) to summarize the data collected during the aerial surveys.

Ground verification was very important in this region, as there are many materials and features that can be mistaken for oil. Extensive black, heavy mineral deposits are extremely common throughout the area on the point bars and mid-channel shoals. The analysis of one sample of this type of material produced a

Table 4 Cleanup map categories used to define the oil residues

1 No visible oil
1A No visible oil—cleanup completed—bag removal required
2 Oil present
Does not meet cleanup requirements—no cleanup recommended
3 Oil present—no cleanup recommended or secondary priority
3A Oil present on cut bank—no cleanup recommended
3B Oil present on non-vegetated shoal—secondary cleanup priority recommended
3C Oil present on vegetated mid-channel island—secondary cleanup priority recommended
3D Oil present in Zone 6 delta flood plain—secondary cleanup priority recommended
4 Oil present—cleanup required
In the July aerial video documentation survey of Zones 6A and 6C, the “category 4” oiling was further subdivided as follows:
4A Large patch (>10 m size) of black-dark oil—to be removed
4B Small or sporadic patches (<10 m size) of black-dark oil—to be removed
4C Large patch of (>10 m size) dull or light brown oil—probably can be raked/mixed
4D Small or sporadic patches (<10 m size) of dull or light brown oil—probably can be raked/mixed

zero TPH (total petroleum hydrocarbon) value. In addition, dark organic (grass and reed) deposits are very common on the flood plains and riverbanks. Other “false positives” observed and ground-checked include burnt vegetated areas, burnt tufted grass bushes (“baja brava”), sheep fecal pellets, and algal mats in Lagos Uru Uru and Lago Poopó.

Weathering

In terms of the character and constituents of the oil residues, the results of the oil chemistry analyses completed shortly after the spill (Little, 2000a; Douglas *et al.*, 2002) show that:

- Volatile aromatic compounds (e.g., benzene–toluene–ethylbenzene–xylene—BTEX) were present in the source oil, but were depleted rapidly and were present at only trace levels in the residual oils and their associated water-soluble fraction.
- Polycyclic aromatic hydrocarbons (PAHs) in the water-soluble fraction of the residual oil were present at trace levels (in the low parts-per-billion) and were almost one order of magnitude lower than in the water-soluble fraction of the source oil.
- From 50% to almost 70% of the total oil and between 71% and 91% of the total PAH had been lost. As a result, the residual oil was primarily heavy hydrocarbons that were both immobile and not readily bio-available.
- The appearance of some “fresh-looking” residual oils may have been due to the character of the remaining components, such as the asphaltene-range hydrocarbons, which leave a tar-like appearance.
- Photodegradation of the oil had been observed in the samples and could be a significant factor in the reduction of benzo[a]pyrene concentrations, especially over the long term at the surface.

These analytical results were available early in the response. The residual oils were thus considered unlikely to pose a threat to human or animal health or well-being. Of particular importance was the fact that the water-soluble fractions had been lost rapidly, within a few weeks if not days, in the weathering processes.

Cleanup Criteria and Cleanup End Points

Four sets of cleanup end points were used during this response, each of which was related to a specific activity or issue: (1) the reopening of the Desaguadero river for normal use, (2) the removal of the oil residues by the cleanup crews; (3) the oiled vegetation in the oiled flood plain, where the local farmers were concerned that oiled vegetation would affect the health of the domesticated animals (sheep, cows, pigs, and llamas), even though chemical analyses of this oiled vegetation showed that it was not a threat (Getter *et al.*, in preparation); and (4) the canals and irrigation ditches, where farmers were concerned that oil in canals would impact crops and watering holes for the domesticated animals. The use of a range of cleanup criteria or end points on one spill is not uncommon (Owens & Mauseth, 2001) and reflects variations in both oiling conditions and in the real or perceived impacts within the affected area.

The first cleanup endpoint was reached on 23 May 2000 when the river was declared “open” following the release of the analytical results from the first phase of an environmental sampling program that was designed to investigate the presence of petroleum hydrocarbons in the river (Taylor *et al.*, in preparation). As part of this study, 129 water samples were analyzed over a period of nearly four months and only one sample collected shortly after the spill exceeded the Bolivian maximum permissible limit of 0.002 mg l⁻¹ of benzene. The study concluded that the waters of the region were in the same state as existed before the accident.

Based on the results of chemical analyses conducted at the outset of the project (Little, 2000a; Douglas *et al.*, 2002) the spilled oil was not considered a threat to human or animal health but, nevertheless, the presence of oil residues was considered unacceptable. The primary motivation for the cleanup operation, therefore, was the removal of the oil residues. Criteria for the completion of cleanup were developed early in the response operation to provide the operations teams with a set of target standards (Table 5). All of the operational zones were signed off by the end of April 2000, except for the large wetland flood plain region in Zone 6 where cleanup was intentionally delayed and which was cleaned after water levels had subsided and the land had dried. A final cleanup phase

Table 5 Sediment cleanup criteria

-
- no 100% oil cover patches >3 mm (1/8 inch) thick and >50 by 50 cm (approximately the size of a shovel),
 - no single patches of >20% surface oil cover >10 m long, >1 m wide, and >3 mm (1/8 inch) thick, and
 - no liquid oil patches >1-m diameter that could be potentially remobilized
-

Table 6 Oiled vegetation removal criteria

- more than 30% of stems with weathered oil or stain, or
- more than 10% of stems with unweathered (fresh or sticky oil)

was undertaken in Zone 6 in December 2000, at the conclusion of which all oil residues that met the cleanup criteria had been removed in all of the operational zones and all bags of oiled and other waste material had been collected and taken to a temporary storage facility.

Once the first phase of the cleanup had been completed in April, the more than 700 local family farmers in the affected wetlands were not convinced by the scientific rationale for completion of cleanup and argued for cutting of the oiled plants. This second-phase cleanup was then carried out and involved cutting more than 80 hectares of vegetation based on a third set of criteria (Table 6) (Taylor, 2000).

Local farmers were also concerned that oil had entered the extensive system of hand-dug canals and irrigation ditches and thus threatened animal watering holes (Comisión de Agua, 2000). Therefore, a fourth set of cleanup criteria was established. Even though, as noted above, the oil residue was not considered an environmental risk, considerable effort was spent sampling man-made canals, ditches, and cattle watering holes to detect oil residues to ensure that the agreed cleanup standard of 500 ppm as detected by photo-ionization detection (PID) had been met. In one phase of this program, 357 analyses were performed on 51 sediment samples and all of the results for toxic components were at the "non-detect" level. In a separate phase of this program 353 stations were analyzed by PID and 59 samples analyzed chemically, and with similar "non-detect" results (Taylor *et al.*, in preparation).

Documentation and "sign-off"

A seven-step procedure was developed for the approval of cleanup activities on an area-by-area basis

(Table 7). The government was presented with the proposed cleanup criteria and the proposed inspection and approval steps in March 2000 but elected not to participate in the process. As a consequence, the "sign-off" process became an internal activity of the response team. Considerable emphasis was placed, therefore, on the systematic and complete documentation of all residues that remained after the cleanup criteria had been met and demobilization had been recommended for a particular area (Owens & Reimer, 2001; Polaris, 2000a; Transredes, 2001).

All of the operational zones were signed off by the end of April 2000, except for the wetland flood plain region of Zone 6 and parts of Zone 5 where cleanup was intentionally delayed. The majority of the areas were signed off by July but the Zone 6 sign-off was not completed until January 2001, as noted elsewhere, due to delays in developing and implementing an access agreement in that area after the wetlands had dried out from the summer flooding (Transredes, 2001).

The oil residues that remained after the completion of cleanup, for the most part, could be categorized as follows:

- oil patches that did not meet the cleanup standards,
- oil present as a thin stain on the riverbanks (bathtub ring),
- small patches of surface oil on non-vegetated shoals,
- patches of buried oil on non-vegetated shoals, or
- small patches of surface oil on mid-channel islands.

Maps and geographic coordinates of all observed residues were included in a series of internal reports that were presented to the government (e.g., Transredes, 2001).

The cleanup of the oiled vegetation initially involved ground inspections by local agronomists to delineate areas to be cut using the criteria defined in Table 6. The locations were defined by GPS coordi-

Table 7 Cleanup inspection and sign-off steps

- (1) The Operations Manager would report that cleanup had been completed on a section of the river, usually one of the operational zones
- (2) The section then would be surveyed and both banks and the mid-channel shoals would be documented by low-altitude (25–50 m) videotape documentation (using concurrent analogue and digital formats) for which GPS (Geographic Positioning System) coordinate fixes were recorded every 3 s
- (3) Ground stops were made at intervals to provide a detailed inspection opportunity and to check for any possible buried oil. These ground spot checks included occasional 25–50 cm deep across-bank pits, still photography (film and/or digital) or video-graphy, and sediment sample collection
- (4) The tape commentary recorded the presence of any sites or areas that did not meet the cleanup completion criteria and these locations were reported to Operations for further cleanup action
- (5) Operations were provided with GPS coordinates and, in some cases, color video frames to assist in the location of the oil and in the evaluation of the level of effort required to remove the oil
- (6) Once the sites had been cleaned the locations were resurveyed to ensure that the cleanup criteria had been met
- (7) For each zone or section of zone that had been surveyed and that met the cleanup standards, a "CLEANUP COMPLETION SURVEY" form was prepared that recommended that sufficient cleanup had been completed

nates and a technique was adopted that used red flags to designate areas to be cut, so that farmers could avoid grazing in these areas, and yellow flags were placed in areas that were considered suitable for grazing (Taylor & Getter, in preparation). The sign-off of those areas that had been cut was based on a ground inspection and followed the cleanup standards. A program of forage replacement to compensate for this oiled vegetation is described elsewhere (Taylor & Getter, in preparation).

The completion of cleaning of the ditches, canals and watering holes was based on the results of chemical analyses using the agreed cleanup standard of 500 ppm as detected by PID. The sampling program for the sediments and waters of these locations was a joint effort with federal, regional, and local government participation.

Cleanup Program

Response operations

Immediately following the accident, a professional oil spill cleanup contractor was mobilized from the United States to provide spill management and response support. The first operational response, on 4th February, was to try to contain floating oil moving down stream. However, by the time of mobilization, the oil had already been carried over 300 km downstream. On-water recovery activities were limited as (a) the oil had already been carried long distances downstream; (b) this is remote area with few roads and bridges that provide access to the river; (c) the currents in the main channels often were in excess of 1 m/s (approximately 2 knots), which precluded the effective deployment of booms directly across the channels; and (d) as outboard motors worked poorly or not at all at this altitude.

The region was divided into operational zones (Fig. 2) and the cleanup operation involved more than 70 experienced zone managers, field supervisors, and health and safety supervisors. All cleanup workers were provided with basic safety training and protective clothing that included boots, work suits, gloves, and safety glasses. During the most active phase of the cleanup, from February through to the end of April, each work crew was supervised by a US-certified Health and Safety officer.

The total labor force included more than 125,000 days of paid work for the local population, including:

- 102,000 days for local cleanup workers,
- 8800 days for support professionals (doctors, nurses, veterinarians, agronomists, and community liaison officers),

- 1000 days for interpreters, and
- 7800 days for field support (drivers).

This work provided a temporary major source of additional income to this impoverished region.

Residual oil cleanup

Specific recommendations for cleanup and treatment tactics were developed for each of the five primary settings in which oil was stranded: (i) river channel flood plains, (ii) river channel cut banks, (iii) river channel point bars and mid-channel shoals, (iv) delta flood plain areas, and (v) irrigation canals and ditches. The guidelines were developed to ensure that cleanup activities did not cause environmental damage, such as the excessive removal of soil or sediment.

The cleanup was conducted primarily by manual techniques, using shovels and rakes. Earthmoving equipment was used effectively only in one area of Zone 2 to remove large oil deposits on a wide, dry point bar. Elsewhere, manual removal was more appropriate as the oil patches were generally small and thin. These manual techniques also minimized the amount of non-oiled material that was removed. Members of the local communities were employed to carry out the cleanup of their own land to avoid inter-community disputes and to divide fairly the amount of work given to each community. Supervisors closely controlled all aspects of the work program to prevent injury and to ensure work quality.

Cleanup was completed in the majority of the areas by the end of April. By 15 July 2000, all seven operations zones were documented and inspected, and recommendations were made for the demobilization of cleanup operations. At that time, all Zones had been recommended for demobilization except for some sections of Zone 6. For this area, a cleanup work plan for removal of the remaining oil was agreed on 4 December 2000.

This final phase of the cleanup activity began immediately with a team of up to 100 supervised local workers and all cleanup operations and bag removal activities in Zone 6 were completed by 20th December 2000. During the period 6–8 January 2001, a field survey of Zones 6A and 6C, using the aerial video-documentation procedures, showed that cleanup had been completed and led to the recommendation for demobilization. This survey completed the inspection and sign-off process and constituted the final action of the cleanup activities for all of the areas that were affected by the spill.

Oiled vegetation removal

The vegetation and natural forage of the Río Desaguadero flood plain south of La Joya, in Zones 5 and 6, were oiled during the period of high water levels immediately following the spill. Cleanup operations were not recommended initially in this region as access through the wetlands was difficult and most likely would have caused additional damage to the vegetation. Vegetation cutting was not recommended as a cleanup option and only was acceptable where ecological or human-use factors were overriding considerations. This recommendation was based on a considerable number of scientific studies and on extensive published literature from prior spills and experiments in a wide range of vegetated habitats (e.g., Baker *et al.*, 1993a,b; Sell *et al.*, 1995; Zengel & Michel, 1996). These and other studies show that oil removal in vegetated areas or cutting of oiled vegetation often has a negative effect on vegetation recovery: that is, these cleanup activities almost certainly would have delayed the recovery of plants.

An interagency Forage Commission had collected samples from natural pastures and from cultivated plants in areas where the upper levels of the stems of plants had been oiled in Zones 5 and 6 (Comisión de Forraje, 2000; Taylor & Getter, in preparation). The amounts of oil on the vegetation were well below the criteria established for the cleanup of residual oil, and the chemical analyses of oiled plant samples showed that the residual oil was non-toxic. In addition, the veterinarians found no mortalities and/or illnesses in animals that could directly be attributable

to ingestion of oiled vegetation (Getter *et al.*, in preparation). Based on these findings, it was evident that the forage was not harmful to livestock, as it did not contain toxic components. Therefore, no additional forage removal was necessary to protect livestock. However, the local farmers expressed the concern that grazing cattle would be harmed if they consumed the oiled stems. Cutting and removal of the more heavily oiled upper stems of forage plants was, therefore, carried out using local labor in order to avoid any possible unforeseen harmful effects to grazing animals.

Manual cutting was carried out using sickles and scythes under the direction of the operations supervisors. Field tests using mechanical grass cutters (weed eaters) showed that these tools were inappropriate as the cut stems and oil were spread over a large area, oiling otherwise clean vegetation and making recovery more laborious. During the period between 27 May and 31 July 2000, approximately 107,300 kg of oiled vegetation were cut from 80.6 hectares of pasture land of Zones 5 and 6. A further 345 bags of vegetation were cut from Zone 6 during November and December 2000.

Cleanup of canals, ditches, and watering holes

The canals, ditches and watering holes that had observed oil were cleaned (Fig. 6) and locations that were suspected to have oil were sampled. After cleanup the sites were re-sampled (Taylor *et al.*, in preparation).



Fig. 6 Cleanup of irrigation canals in Zone 5C, 17 March 2000.

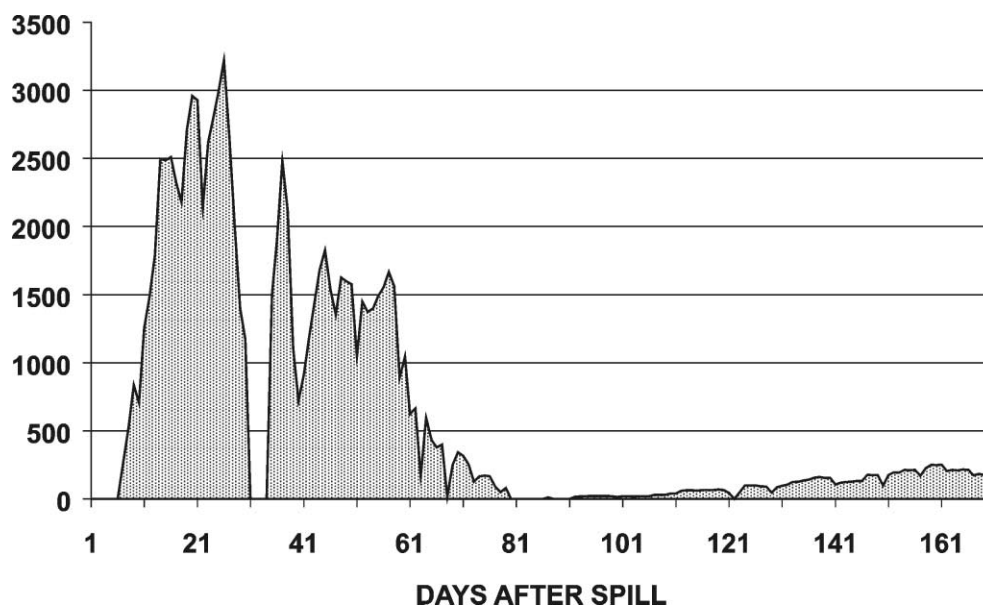


Fig. 7 Number of local laborers in the cleanup force: Day 1 = February 3rd 2000 and all operations closed down between Days 31 and 34 (March 4th to 7th) due to "Carnival".

Manpower levels

Within a week of the start of the response operation the local labor cleanup force had reached 400, by the end of the second week it had reached over 1500, and it peaked at 3200 workers in early March (Day 26) just before Carnival (Fig. 7), and thereafter diminished to Day 80. The work force increased again until the end of July as vegetation cutting proceeded and again in November and December as cleanup work in Zone 6 was completed. The support labor force increased and decreased in the same manner as the local field labor force until the end of April. Field support included operations supervisors, health and safety officers, drivers, interpreters, and logistics personnel. For the third phase of cleanup, in Zone 6 in November and December, the local labor force reached almost 100 workers.

Operations constraints

As a result of the lowered oxygen content of the atmosphere at this 3500 m elevation, combustion engines are inefficient at best (Owens *et al.*, 2001). Outboard motors for river work were ineffective so that booms had to be deployed by hand in the initial days of the response. Fixed- and rotary-wing aircraft operations were similarly limited so that fuel- and payloads had to be drastically reduced compared to operations at lower altitudes. In particular, survey activities in Zones 1 and 2 were as much as 300 km from the airport at Oruro and involved the use of ei-

ther fuel caches or coordinated support from a mobile fuel truck.

Access and movement were limited as there are few paved roads in the areas adjacent to the river and only seven bridges cross the river in the affected area. Initial boom deployment was predicated on the location of these bridges and their associated roads. During the flood period the river could be crossed only at the bridges and at three commercial hand-drawn ferry locations. Many truck loads of waste material were hauled from the right (south) bank of the river by these ferries to the storage location on the north side of the river. Again, efficiency was limited in Zones 1 and 2 by the lengthy transit distances from the operations base at Oruro (Fig. 2). Access in the wetlands of the flood plain zone was very difficult during the winter season and a decision was made early in the spill to delay cleanup in these wetlands to avoid vehicle damage to the soil and vegetation.

Waste Management, Bag Removal, and Final Disposal

The cleanup operations generated a wide variety of waste materials that included sediments, vegetation, protective equipment, sorbents, packing materials, plastic bags, and water bottles. Some of these materials were oiled and some were not oiled. However, all materials were removed and placed in two off-site lined waste pits and now should be assumed to be mixed with the oiled materials. The materials in the pits can be categorized as follows:

- Oiled plastic-based materials including clear (approximately 6 mil thickness) plastic bags, used latex gloves and used protective work suits.
- Oiled sediments varying from heavily to lightly oiled, inorganic sediments that are mostly fine-grained sands with varying clay content.
- Oiled vegetation, mostly *totorales* reed.
- Liquid oil or oily liquids.

As a result of the oil removal operations, approximately 860,000 bags of oil spill cleanup waste were generated. These bags and other waste materials were placed in the two lined pits that were sealed with a surface liner and a sediment overburden in December 2000 after the completion of all operations, pending a decision on the final disposal process.

Discussion

Oil budget

The results of the chemical analyses show that the average loss due to combined evaporation, volatilization, and other weathering and degradation processes was on the order of 60% (Douglas *et al.*, 2002).

The amount of recovered oil was very difficult to estimate as the proportion of oil to sediment or vegetation varied greatly from one site to another. Typically, the amount of oil in waste when manual recovery techniques are used is on the order of 1–5% by weight. Therefore, for a 15 kg bag of waste, which is the approximate overall average, the amount of oil would be on the order of 0.17–0.83 l of oil per bag. The calculation of recovered oil used in this budget is based on the assumed averages and on the count of number of bags of oiled waste. Using this approach indicates that the cleanup operations recovered as much as approximately 4000 bbl of surface oil. This indicates that the degree of oiling was relatively light overall, particularly considering that the oil was deposited along a total of approximately 400 km of the river, often on both banks, and on several hundred hectares of the delta flood-plain south of La Joya. This overall light oiling condition is consistent with the field observations.

Table 8 presents a “budget” estimate for the spilled oil based on calculations made in early June 2000. The amount of oil remaining and the unaccounted balance included: (a) small patches and stains below the cleanup standard, (b) buried oil, (c) oil on vegetation, and (d) oil dispersed in the river by physical processes.

The “unaccounted balance” figure appears high until the physical processes in the river at the time of

Table 8 Oil spill budget estimate

	Barrels	Liters
Amount spilled	29,000	4,611,000
Amount remaining after natural evaporation and volatilization	Est. 11,600	Est. 1,844,400
Recovered by cleanup operations	Est. 750–3800	120,000–600,000
Remaining surface oil (June 2000)	Est. 10–50	1600–8000
Unaccounted balance	7750–10,840	1,236,400–1,723,000

the spill are considered. The extremely high physical energy levels undoubtedly were sufficient to entrain and rapidly physically disperse much of the oil into very small particles and to promote the formation of oil–water–clay emulsions (Douglas *et al.*, 2002; Lee *et al.*, 2002). These emulsions then would have been subject to biodegradation. Most of the entrained and dispersed oil likely would not have been carried any long distance downstream, perhaps only a few tens of kilometers at most. Bottom sediment samples indicate that this dispersed oil did not accumulate on the riverbed (Taylor *et al.*, in preparation). Samples collected from the Lagos Uru Uru and Poopó areas are devoid of hydrocarbons, so that oil did not leave the Desaguadero system. The flood plains below La Joya acted as an effective natural filter to any oil that reached that area.

This “unaccounted balance” also includes an unknown volume of subsurface oil that undoubtedly existed in June in the dynamic channel-margins shoals, where sediment transport would have buried oil that was not removed by the river currents. This volume is estimated to be very small, based on field observations and on occasional pits dug throughout the affected area. Buried layers of oil had been observed at a few locations on the flood-plains of Zones 5 and 6. These areas were not extensive, perhaps in total no more than one or two hectares, and the observed layers were very thin, generally only 1 or 2 mm thick, and had a high sediment content (Douglas *et al.*, 2002).

Fate of the remaining oil residues

The results of chemical analyses of the oil residues completed shortly after the spill showed that the spilled oil had weathered rapidly. The BTEX fractions had been reduced to levels below the reporting limits for both the residual oil and the water-soluble fraction (Little, 2000b; Douglas *et al.*, 2002). For the PAH's, there was almost complete weathering of the light-end PAH compounds (naphthalenes) and approximately 85% of the total PAH's were depleted. Perhaps more importantly in this river spill there was virtually a complete loss (90%) of the water-soluble fractions.

The small amounts of oil that did not meet the cleanup criteria and that remained after the completion of cleanup were not considered a threat to humans or animals. The remaining surface oils that were observed during the sign-off inspections were visibly undergoing rapid deterioration and this weathering is evidenced by analytical results. These residues generally were very friable and almost completely disintegrated when disturbed with a shoe. These deposits typically were very small in size, a few square centimeters, and very thin, usually only 1 or 2 mm thick. They were subject to frost, wind action, and high levels of insolation that are typical of this region during the winter months. Some stains and patches persisted until the 2000–2001 summer rainy season when the highly weathered and uncohesive residues were washed out by the rains or removed by the flooding waters.

The majority of the “bath-tub ring” stains observed on the river banks in the weeks after the spill were eroded by current action during high-water levels in March. Those stains that remained at that time are documented (Polaris, 2000b) and were expected to further degrade in place. Some residues may have survived through the winter until they became subject to erosion during the next period of high water levels in the summer rainy season.

The last field survey was conducted in January 2001, immediately prior to the summer floods. However, the following comments are presented on the anticipated fate of the remaining residues after that time.

The small amounts of oil that have been buried in the mid-channel shoals had become encased by the drying sands. These patches of subsurface oil remained enclosed in the hard substrata until the summer 2001 rainy season when, it is speculated, they almost certainly would have been subject to erosion and to the intense levels of physical energy that removed so much of the spilled oil in the few days and weeks after the incident.

The patches of oil that were buried on the flood plains of Zones 5 and 6 often were visible in mud cracks, as the thin surface layer of wet sediments that had covered them in these areas has dried out. This buried oil generally was only a few centimeters below the surface, had a high sediment content, and had a very weathered appearance in most cases. The oil that was exposed in the mud cracks was subject to weathering during the winter, but, again it is speculated, the majority of this buried layer remained until it would have been washed and removed by the flood waters of the summer rainy season. Some patches may persist for longer in areas that were not covered by the summer floods of 2001, but this is unlikely as the discharge volumes were higher and the flooding was more extensive than observed in the summer months at the time of the spill.

Summary and Conclusions

Cleanup of the oil residues commenced within a few days following the spill (Table 9) and the cleanup operations removed oil to the levels defined by the cleanup criteria that were established early in the project. The video documentation and inspection program that was implemented to guide the completion of the operations has documented the location of the oil residues that remained after the completion of the cleanup in each zone. The monitoring program and the oil characterization study have documented that these residues have degraded considerably over the period following the completion of cleanup, and therefore were not a threat to the environment or to human or animal health.

The linear stain that was present along the riverbanks and documented by the survey program had disappeared already in many areas prior to the 2001 rainy season.

The volume of spilled oil initially was reduced by about 60% due to a combination of weathering processes. Relatively little oil was recovered by the cleanup operations as the degree of oiling was relatively light overall, particularly considering that the oil was deposited along a total of approximately 400 km of the river, often on both banks, and on several hundred hectares of the delta flood-plain.

During this response operation four sets of cleanup end points were developed to address different issues: (1) the reopening of the Desaguadero river for normal use; (2) the removal of the oil residues (Table 5); (3) the oiled vegetation (Table 6); and (4) the canals and irrigation ditches, where farmers were concerned that oil in canals would impact watering holes for the domesticated animals. The amounts of remaining weathered surface and buried oil following the completion of cleanup operations were very small, perhaps only some tens of liters, based on extensive ground observations throughout the affected area.

Table 9 Summary of key dates

Spill	30 January, 2000
Cleanup of residual oil commenced	First week of February
Cleanup labor force maximum	28 February
Residual oil cleanup standards proposed	3 March
Inspection and documentation surveys	28 February–8 March, 19 March–30 April
End of first cleanup phase—majority of oil residues removed from Zones 1 through 5	30 April
Río Desaguadero declared open	23 May
Vegetation cutting commenced	27 May
Inspection and documentation survey	6–15 July
End of first vegetation cutting phase	31 July
Zone 6A and 6C residual oil removal and cutting commenced	5 December
Cleanup in Zone 6A and 6C completed	20 December 2000
Zone 6 inspection and documentation survey	6–8 January 2001

The majority of the small amounts of remaining friable and weathered surface oil did not survive winter weathering processes. Only a few stains and patches persisted until the 2000/2001 rainy season and only a few isolated "bath-tub ring" stains on the river banks, which degraded in place, survived the winter.

The small amounts of oil that had been buried in the mid-channel shoals had become encased by the drying sands and it was expected that these would be eroded by current action during the summer floods. Similarly, the patches of oil that were buried on the flood plains of Zones 5 and 6 would have remained until washed and removed by the summer 2000/2001 flood waters.

Oil that remained on plant stems became part of the litter to be degraded by bacterial and microbial action as the plants go through their annual cycle of die back during the winter months. It is unlikely that any of this oil will persist beyond the spring 2001 as unused pastures are usually burned annually.

The oil from the 30 January spill was spread over a large geographic area but was cleaned up successfully and rapidly, in three months, by a large response operation that involved over 3600 people. Secondary cleanup activities after April 2000 focused on oiled vegetation and on man-made canals, ditches and watering holes. Cleanup completion was guided by sets of criteria that were developed to address specific environmental conditions.

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