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EnRiMa ConMa

Environmental risk Management for contaminated marsh land in Khanty-Mansiysk

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Knowledge Mapping Report

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1 Summary

This report presents the current situation and related environmental problems of oil contaminated sites in the Khanty-Mansiysk Autonomous Okrug (KMAO) in Russia. The natural characteristics of the area are described as well as the current Russian legislation. Also, the Russian partners (Sibnipirp and Rusecosystem) present the current knowledge about the ecological impact from application of different remediation techniques used in the region. Common remediation techniques for oil contaminated soils in Europe are presented as well as the resulting information of a literature survey made by the European partner (IVL).

At present there are 278 oil-fields under development in KMAO. Annual oil production at 53 of them exceeds 1 million tons. In 2006 average daily oil production reached 755 thousand tons. The techniques used for oil extraction lead to substantial damage of environment in the territory of KMAO-Ugra. Most oil spills are the result of pipeline rupture with 96 cases from 100 caused by corrosion processes. Analysis of the oil spills from pipelines due to corrosive wear made by oil-and-gas companies of KMAO indicated taht the average operating life of field pipes before the first incident is 2–3 years. Analysis of official data over 14 years shows that the average number of oil spills in oilfield system over the period 1991–2004 is 1600–2000 failures per year. The peak levels of the oil spill rate were in the middle of 90s and in 2004. Number of oil spills shows steady and increasing tendency during last few years.

Enhanced oil extraction used in great number of fields means that massive volumes of produced mineralized water are injected into the oil-bearing bed, consequently there is not oil extraction but extraction of so-called "oil containing water". In this connection, according to the official data, percentage of crude oil to the total volume of polluting substances is 3–5%; the rest is volume of formation waters. Total salinity level of such waters is 20-30 g/l. Usually the contaminated area is assessed by the area of oil spill excluding saline contamination (it is not referred to the major accidents on water pipelines). On the drained dry lands chlorides are washed out in 1–2 years, whereas they keep toxicity for decades after elimination of oil pollution in wetlands, especially in wetlands without or with poor outflow.

The climate of the region is extremely continental, with long and inclement winters, wanton springs, brief summers and short autumns. The period when the temperature is below 0°C lasts for 7 months – from October till April. Mean January temperature in the region varies from – 18°C (in the south) to – 24°C (in the north). Hydrographic network of KMAO refers to the Kara Sea basin. It includes a great number (19.6 thousand) of water passages, lakes, swamp lands, which is caused by the overmoistening of land, flat surface pattern and close occurrence of impervious horizons. Easy gradients of the land cause slow river flow and a high degree of sinuosity of the rivers. Big rivers have wide valleys with two-sided sharply meandering flood-plains. River channels abound in branches, creeks and lakes. A weak drainage effect of the rivers is one of the most important factors of overmoistening and bogginess. The degree of bogginess of some gathering grounds is more than 50-70%. Thus soil and weather conditions of the region are extremely severe for the process of oil biodegradation. Soil overmoistening on the one hand hampers deep penetration of oil, but on the other hand it complicates recultivation from the point of technical and agrobiological operations.

It should be noted that regulatory system for assessment of oil contaminations in KMAO-Ugra and in Russia itself is weak. To assess ecological risks it is necessary to have strict guidelines for oil

and oil products content in soil. What's more these guidelines must be differentiated with respect to surface pattern of the polluted land, its status and the age of the oil spill. Scientific findings are numerous but they are uncoordinated and sometimes contradictory. All that makes it impossible to use these findings as objective criteria for ecological risks assessment. In 2004 the Government of KMAO-Ugra approved the regional norms "Permissible oil and oil products residues after recultivation and rehabilitation of land in KMAO-Ugra" which differentiated MPC of oil with respect to functions of areas, types of soils and its features. The advent of regional norms is the step forward despite of the fact that these standards work mainly for new oil spills, whereas there are a lot of old (>2 years after the incident) spills.

To reduce oil concentration in soil to the permissible level, rotary cultivation with injection of bacteria and nutrients is performed in the oil contaminated area. The rotary cultivation is set as a standard remediation technique in the region. There are reasons to consider this type of recultivation more harmful for marshes and environment itself than high concentration of low-toxic oil components in soil, since it destructs the active layer of peat deposit, where mass- and energy interchange takes place. This active layer formed from subshrubs roots and mossy tirr is able to swell when it's moistened and to compress when it's drained. After the impact of rotary cultivation and heavy mechanical equipment the top layer actually loses ability of self-recovery of water-air regime. As a result, the top layer become weather-dependant (in a case of vast rainfall – the area is flooded; otherwise – fast drainage); in other words such contrasting water-air regime negatively influences on the growth of plant-meliorates. Rotary cultivation results in rise of strongly acidic sterile peat, non-applicable for vegetation; as well as in travel of oil-contaminated peat from active layer into anaerobic conditions. The major negative effect comes from surface injection of phosphorous fertilizers, which are weak water-soluble. As a result, toxic phosphorous concentration accumulates in the upper layer of peat deposit, whereas root layers lack of phosphorus. It's obvious that fertilizer and lime treatment in oil-polluted heavily saline peat soils leads only to deterioration, as it increases osmotic pressure of soil solution, which is responsible for drying out of plants and inhibition of microflora development. Negative impact is also marked by correlation indexes between pH of water and saline extracts and total projective cover degree.

Today the main remediation goal of oil contaminated marsh lands is reduction of oil concentration in soil up to the level of normative regulations. It is usually done by means of excessive negative impact on ecosystem unequal to real damage rate of biocenosis. There is no unique recultivation method suitable for every soil and weather conditions. That's why it is important to elaborate specific techniques and operations of recultivation, that are able to take into account all features of every oil-contaminated area and thus making rehabilitation of damaged biocenosis faster. More research and exchange of knowledge is needed regarding the degradation of oil and the toxicity of oil in wetland areas. The nature in Khanty Mansiysk is unique and hydrologic regimes are vital for the survival of the ecosystems in the region. The currently used remediation technique of rotary cultivation helps to dilute the oil but it destroys the function of wetlands and it affects the hydrologic regime. A risk assessment tool for the area needs to be able to weight the effects of different remediation techniques on ecotoxicity as well as hydrology and groundwater. A risk assessment tool also needs to predict the consequences of remediation in a long term perspective. More, it should also consider the combined effects of oil and high salinity water into freshwater systems.

Inefficient monitoring system controlling polluted and recultivated areas aggravates ecological risks. Oil companies are to furnish monthly accounts to national and regional inspection bodies, which should include number of failures, accidental spillage volumes and area of pollution. These oil-contaminated areas are under examination of inspectors, but vast territory of oil fields and lack of inspection body personnel make it impossible to carry out thorough examination of an oil field and those polluted parts which haven't been reported about by companies owning them. One of the most important tasks to fulfil that can help the future situation of oil spills in the region is thus to find a cost effective way of preventing and detecting oil spills. This is closely related to the legislation and physical planning of oil exploration areas. In recent years the vast majority of oil producing companies pays much attention to oil spill prevention. They realize examination, defectoscopy and anticorrosive treatment of field pipelines, their reconstruction; they use pipes with advanced corrosive resistance and improve system of failure detection and reporting. The literature study indicates that the Russian oil industry and Russian authorities could benefit by the prevention and control plans that have been set up in other oil exploration areas (mainly Alaska).

The weakness of the currently used monitoring and risk assessment system can be summarized in:

- limited resources for surveillance of the number and spatial distribution of oil spills
- inefficient monitoring system controlling polluted and recultivated areas;
- present remediation techniques and criteria is not in conformity with good environmental practice
- absence of recultivation techniques applicable for oil-contaminated marshes and adopted to local conditions
- absence of differentiated guideline values for oil pollution and related ecological risks assessment
- absence of objective criteria for inspection of recultivated areas, ranked according to ecological risks
- lack of knowledge regarding plant species optimal for bioremediation of oil contaminated peat and harmonized with native flora
- weak description of oil spill impact in a river basin perspective
- weak description of oil spill impact in a long term perspective
- weak understanding of the full impact of high salinity water (formation water) discharged from oil drilling activities

Next step in the project is to suggest the way forward to reach the needed improvements mentioned above. It will be done by information exchange between partners and stakeholders of the possibility to develop and adjust other remediation technologies as well as adaptation of risk assessment methods used in other countries. The discussions will also result in prioritization of future research projects regarding oil contamination in the region.

2 Introduction

Khanty-Mansiysk Autonomous Okrug (KMAO) in Russia faces a strong demand for efficient remediation strategies for oil contaminated marshes. KMAO is an important oil producer with regions that have large contaminated sites due to the oil production and transportation.
The project aims to establish a strong research network with partners from Europe and Russia in order to help identify gaps and to supply the needed knowledge for improvement and development of regional strategy and a risk management system for oil contaminated marshes.

This report is a result of the knowledge-mapping activities and describes the background situation with existing problems of oil contamination in the KMAO region, the guideline values and remediation techniques used and the subsequent identified knowledge gaps. Remediation techniques for oil contaminated soil from other parts of the world is presented and discussed briefly as well as sorbent materials and guideline values. The purpose of the report is to collect and summarize current national (Russia) and international information about remediation techniques and problem solving for oil contaminated marsh lands. Next step of the project phase is to evaluate and discuss the collected information and to develop a strategy for further research and innovation of riskassessment for oil contaminated marsh lands in the Khanty Mansiysk region in Russia.

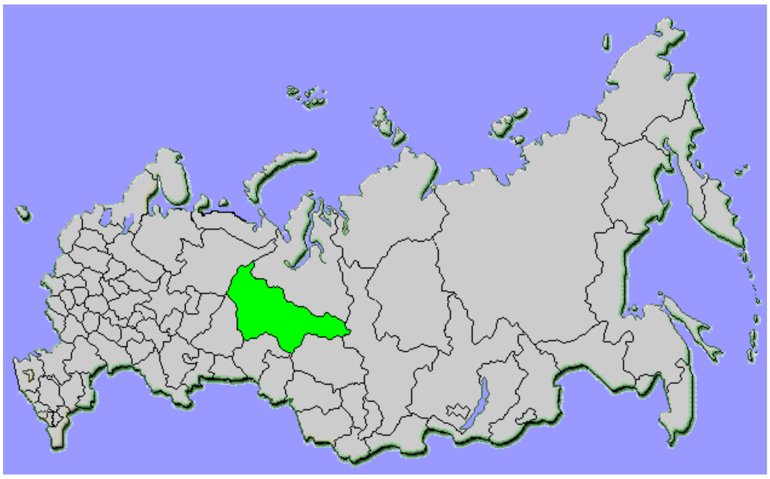
3 Description of oil contamination and remediation in KMAO-Ugra

3.1 Oil-contamination of lands in KMAO-Ugra

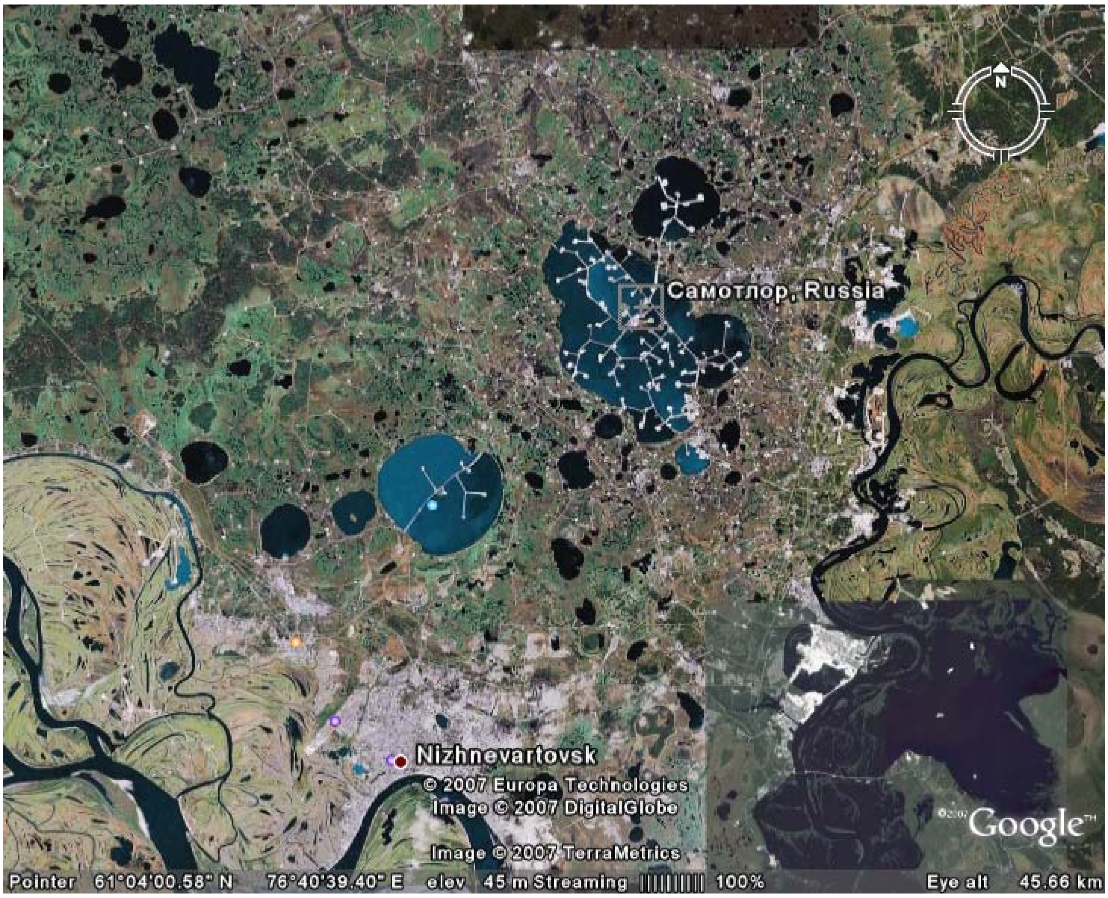
KMAO-Ugra is a region in Russia situated east of the Ural Mountains in Siberia (fig 1.A) The oil extraction in the territory of Khanty-Mansiysk Autonomous District – Ugra (KMAO-Ugra) equals to 57% from the total oil extraction in Russian Federation and to 7.2 % from the world oil extraction. The cumulative oil production in the territory of KMAO-Ugra has reached 8604.9 million tons during the period from the initial field development in 1964 up to 01.01.2007.

At the present moment there are 278 oil-fields under development in KMAO. Annual oil production at 53 of them exceeds 1 million tons. In 2006 average daily oil production reached 755 thousand tons. In figure 1.B it is demonstrated that oil exploration is going on in an area with a very high number of small lakes and wetlands. Roads and pipeline systems are constructed even out in the lakes.

KMAO-Ugra region comes first not only in oil extraction but in the failure rate of field pipelines as well. Most oil spills are the result of pipeline rupture with 96 cases from 100 caused by corrosion processes. Analysis of the failure rate of field pipelines due to corrosive wear made by oil-and-gas companies of KMAO indicated the average operating life of field pipes before the first incident that is 2–3 years. Analysis of official data over 14 years shows that the average number of failures in oilfield system over the period 1991–2004 is 1600–2000 failures per year. The peak levels of the failure rate were in the middle of 90s and in 2004. Number of failures shows steady and increasing tendency during last few years (fig. 2). The outflow of oil-contaminated water during the same period reaches 3.7 thousand tons (excluding 1996 with its maximum outflow of oil – more than 33.5 thousand tons). The average outflow of oil-contaminated water as a result of a single failure is more than 3 tons while in 1996 this number reached 12.6 tons.



Figur 1.A. Map of Russia with the Khanty Mansiyisk region marked in green.



Figur 1.B. Oil exploration near Nizhnevartovsk (from Google Earth).

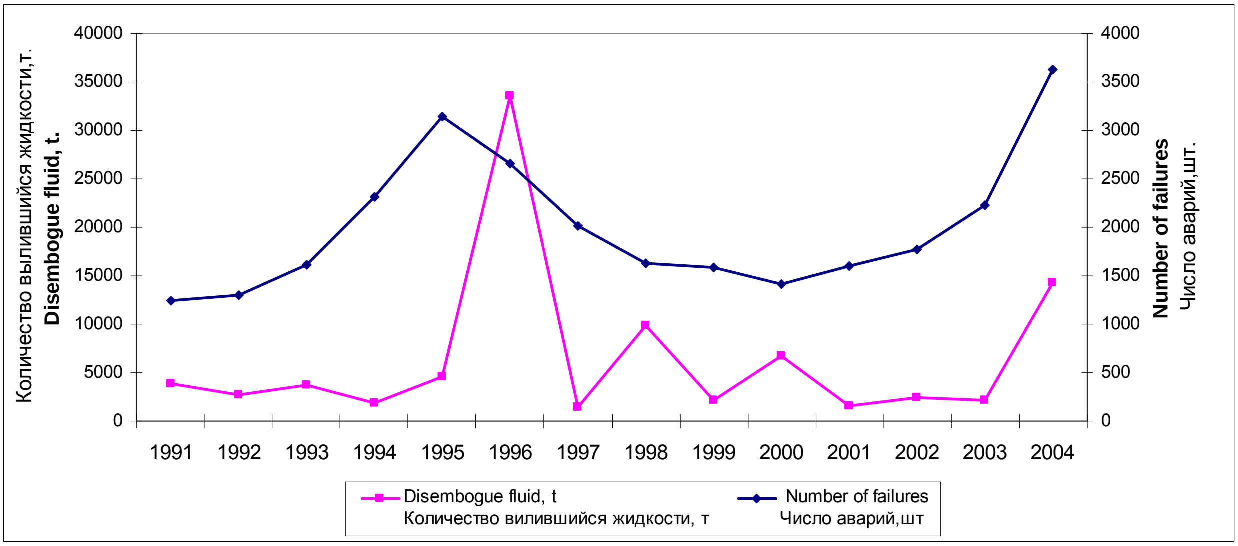


Figure 2. Failure trends at oil fields in the territory of KMAO-Ugra

Apparently, vast volumes of oil extraction lead to substantial damage of environment in the territory of KMAO-Ugra. Members of Russian ecological congress, held in 2007 in Khanty-Mansiysk pointed out following principal reasons for the high level of man-made pollution in the regions producing oil and gas:

- great number of accidental spills of oil, oil products and by-products;
- slow pace, scope and quality of recultivation, which cannot guarantee ecological rehabilitation of the oil-contaminated territory.

At the International conference “Biological recultivation and monitoring of disturbed industrial lands”, held in June 4-8 2007 in Ekaterinburg, it was concluded to apply with request to the governmental authorities of the regions and republics of Russian Federation for greater government control over choice of recultivation route, over quality of the performed works and their compliance with legal requirements and regulations. Significant differences in standards for mineral and peat soils made it necessary to amend some region regulations concerning recultivation of oil-contaminated bogs according to the requirements of the national environmental law and the basic principle of recultivation process that is natural biocenosis rehabilitation.

The Ecological Research Institute of natural resources management on the basis of The Tyumen State University discovered 611 oil-polluted areas (more than 750 hectares) within the territory of the Uganskneftegas Company (a well-afforested south part of KMAO) (table 1). Analysis of habitat confinedness confirmed that every second oil spill and 2/3 of the polluted areas fall at different types of marsh lands. According to the characteristics of oil spreading, it became clear that there is an obvious disproportion between the trace amount (26%) of vast oil spills (more than 1 ha) and the fact that 85% of the contaminated areas fall at them (table 2).

Table 1. Characteristics of habitat spreading of oil pollution within the territory of the Uganskneftegas Company.

Habitats	**Number of oil-polluted areas**	**Number percentage, %**	**Polution area, ha**	**Area percentage, %**
Marsh lands	338	55.4	516.81	68.6
Water surfaces	106	17.3	27.82	3.7
Mineralized	13	2.1	10.21	1.4
Wooded lands	128	20.9	153.42	20.4
Inundable	20	3.3	43.16	5.7
Others	6	1.0	1.39	0.2
Total	611	100	752.81	100

Table 2. Characteristics of oil pollution according to the areas of oil spills within the territory of the Uganskneftegas Company.

Size of spills	**Number of oil-polluted areas**	**Number percentage, %**	**Pollution area, ha**	**Area percentage, %**	**Average size of spills, ha**
< 0.1 ha	192	31.4	9.55	1.3	0.05
0,1-1.0 ha	259	42.4	107.13	14.2	0.41
> 1.0 ha	160	26.2	636.13	84.5	3.98
Total	611	100	752.81	100	1.23

Hereby, an average vast spill occupies the area of 4 ha. Medium oil spills (0.1–1 ha) are the most numerous spills. In particular, within the territory of Mamontovskoe oil field heavily polluted areas prevail either by concentration or by total area of pollution, where 85% of new oil spills are heavily polluted.

During the inventory of oil-contaminated lands in the eastern marsh ridden part of KMAO, made by experts of SibNIPIRP 8417 areas (of 4417 ha) were investigated. Besides, polluted lands mainly occupy marsh lands (86%) and man-made grounds (12%), where man-made grounds are sand banking for processing facilities (table 3). The vast majority of the contaminated lands are mildly polluted; they are mainly of a small size. That’s why their percentage of the total pollution area twice as small as that of medium polluted lands (table 4). The fact that polluted areas mainly occupy water-logged habitats (bogs in general) has influenced the depth of pollution (table 5) – it does not exceed 15 cm on the 95% of the number of areas.

Table 3. Characteristics of habitat spreading of oil pollution in the eastern part of KMAO-Ugra.

Habitats	**Number of oil-polluted areas**	**Number percentage, %**	**Pollution area, ha**	**Area percentage, %**
Marsh lands	6153	73	3814	86
Dry wooded lands	112	1	75	2
Man-made grounds	2152	26	528	12

Table 4. Characteristics of pollution rate in the eastern part of KMAO-Ugra.

Pollution rate	Number of oil-polluted areas	Number percentage, %	Pollution area, ha	Area percentage, %
Heavy	2064	25	1505	34
Medium	3059	36	1907	43
Mild	3294	39	1005	23

Table 5. Characteristics of soil pollution depth in the eastern part of KMAO-Ugra.

Depth of pollution, cm	Number of oil-polluted areas	Number percentage, %	Pollution area, ha	Area percentage, %
0-5	2960	35	980	22
5-10	3148	38	1942	44
10-15	1868	22	1184	27
> 15	441	5	310	7

The total oil polluted territory in KMAO-Ugra is not figured yet for the reason of underreporting of oil spill volumes and polluted areas made by oil and gas companies to avoid penalties. The other reason is absence of global regional inventory due to lack of proper financing. According to experts the total polluted area in the region reaches 10 – 40 thousand ha. At the same time aero- and satellite imagery brings overcharged figures; field surveys lack for detailed information, besides this kind of information is not available for intensive study due to its commercial purposes.

Enhanced oil recovery used in great number of fields means that massive volumes of produced mineralized water are injected into the oil-bearing bed, consequently there is not oil extraction but extraction of so-called “oil containing water”. In this connection, according to the official data, percentage of crude oil to the total volume of polluting substances is 3–5%; the rest is volume of formation waters.

Total salinity level of such waters is 20-30 g/l. The greater ecological danger lies in chlorides in view of their high mobility and toxicity. In a case when oil penetrates into ground no further than the ground water depth, in that case chlorides contaminate the whole peat bed, easily migrates to the adjacent areas and posses much stronger toxic effect than oil.

Usually the contaminated area is assessed by the area of oil spill excluding saline contamination (it is not referred to the major accidents on water pipelines). On the drained dry lands chlorides are washed out in 1–2 years, whereas they keep toxicity for decades after elimination of oil pollution in wetlands, especially in wetlands without or with poor outflow. In present work only ecological risks connected with oil contamination of marshes are under examination. However, it is important that saline contaminations associated with oil spills intensify toxic action on biocenosis and decreases effectiveness of recultivation of oil-polluted areas.

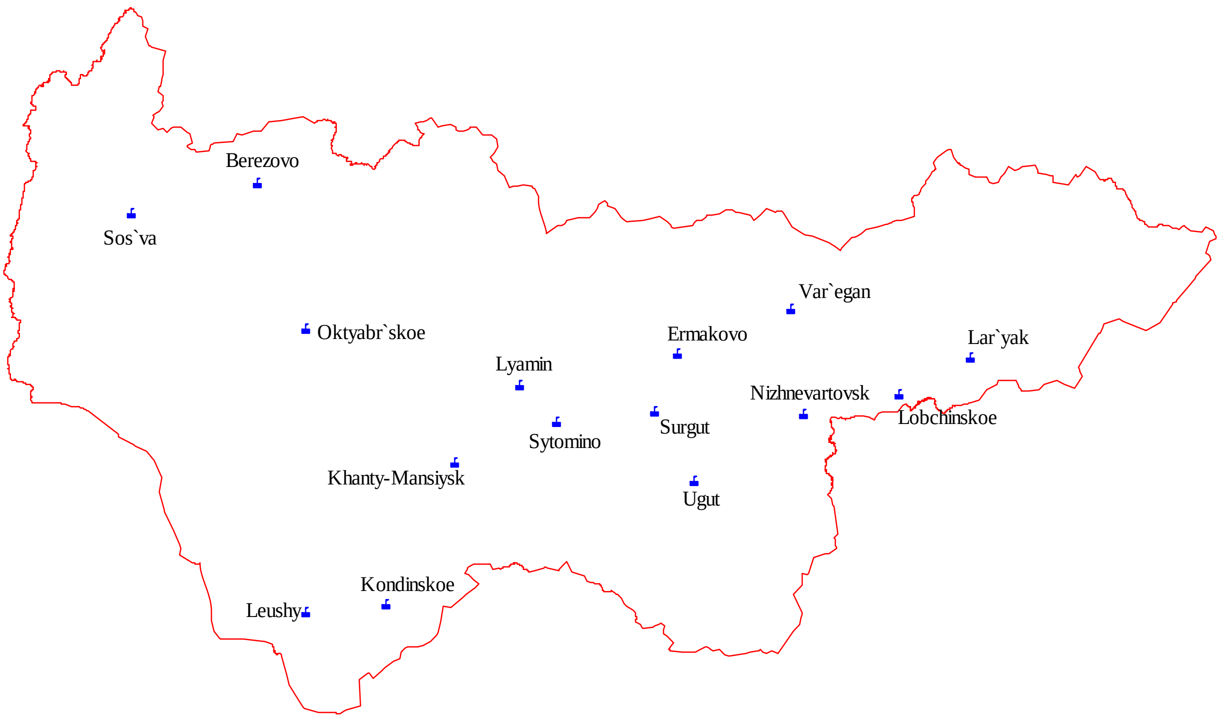
3.2 Natural Climatic Characteristics of KMAO

3.2.1 Climate and temperature

The climate of the region is extremely continental, with long and inclement winters, wanton springs, brief summers and short autumns. Sudden changes of the weather are very characteristic in any season of the year, especially in periods of transition from autumn to winter and from spring to summer. By the sudden change of air masses, amplitude of diurnal variation of temperature is within 10-20°C.

The period when the temperature is below 0°C lasts for 7 months – from October till April. Mean January temperature in the region varies from – 18°C (in the south) to – 24°C (in the north).The frost-free period lasts for 80-110 days. July is the warmest month; the mean temperature is +15.7-18.4. Almost every year the temperature of separate summer days reaches 30-34°C. The vegetation period in the region lasts from 60 days (in the north) till 115 days (in the south). Annual solar output reaches 3100 MJ/m² (in the north) up to 3600 MJ/m² (in the south). In winter (period from November to January) sparse insolation prevails. The maximum of direct beam radiation is marked in summer and it equals to 46-57% of the solar output.

Information about long-term observations of mean temperature in KMAO is given in table 6. The location plan of weather stations is shown in figure 3.



Picture.1 The location plan of weather stations

– Borders of KMAO - Yugra, – weather stations

Figure 3. Location of the weather stations in Khanty Mansiysk.

Table 6. Monthly mean temperature, °C.

Station	Months												Year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Var'egan	-22.8	-22.1	-13.7	-4.8	3.0	12.6	17.7	13.2	7.1	-3.5	-15.1	-21.1	-4.1
Ermakovo	-22.5	-20.1	-13.7	-3.9	3.5	12.7	17.0	13.6	7.2	-2.1	-14.1	-21.2	-3.6
Gorshkovo	-21.4	-19.3	-12.6	-2.6	4.4	12.9	16.8	13.6	7.2	-1.6	-13.2	-20.2	-3.0
Sytomino	-21.8	-19.5	-13.3	-3.3	4.4	13.1	17.0	14.0	7.5	-1.5	-12.9	-20.0	-3.0
Lar'yak	-22.4	-19.4	-12.5	-3.3	4.4	13.2	17.1	13.6	7.8	-1.9	-14.6	-21.6	-3.3
Surgut	-22.0	-19.6	-13.3	-3.5	4.1	13	16.9	14.0	7.8	-1.4	-13.2	-20.3	-3.1
Lobchinskoe	-22.4	-19.0	-12.0	-2.6	4.8	13.3	17.0	13.9	7.7	-1.9	-14.0	-21.2	-3.0
Khanty-Mansiysk	-19.8	-17.4	-11.4	-0.7	6.6	14.3	17.5	15.0	8.4	-0.7	-10.7	-18.1	-1.4
Ugut	-21.4	-18.0	-11.3	-2.0	5.3	13.4	16.9	13.8	7.8	-1.2	-12.9	-19.8	-2.4
Nizhnevartovsk	-17.8	-11.1	-8.0	-4.7	7.4	15.5	17.0	12.4	6.0	-0.8	-12.7	-24.7	-1.8
Kondinskoe	-19.8	-18.4	-10.1	0.1	8.4	14.9	18.7	14.7	8.9	-0.6	-10.2	-16.3	-0.8
Berezovo	-22.3	-19.8	-13.4	-4.3	2.9	11.2	15.9	13.0	6.8	-2.8	-13.3	-19.7	-3.8
Leushy	-18.1	-16.2	-8.5	1.6	8.4	14.9	17.8	14.9	8.9	0.3	-8.8	-15.9	-0.1
Oktyabr'skoe	-22.8	-20.1	-10.2	-2.2	4.7	12	16.9	12.6	7.2	-2.9	-11.7	-18.1	-2.9
Sos'va	-22.7	-20.4	-12.0	-1.8	5.2	12.3	16.1	12.8	6.6	-2.5	-12.8	-20.2	-3.3

Table 7. Long-term data of mean monthly and annual rainfall, mm

Stations	Months												Year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Var'egan	21	17	21	27	48	65	75	81	64	48	38	32	537
Ermakovo	28	21	23	24	39	66	73	86	64	63	42	36	565
Gorshkovo	18	14	18	23	41	55	64	69	51	46	32	28	459
Sytomino	18	14	18	23	41	55	64	68	52	43	32	27	455
Lar'yak	14	13	15	23	50	64	75	80	57	44	29	23	487
Surgut	22	17	21	24	47	59	72	75	59	50	35	28	509
Lobchinskoe	16	16	16	27	54	70	81	87	65	49	32	27	540
Khanty-Mansiysk	23	19	22	25	48	55	67	65	54	48	37	31	494
Ugut	25	20	24	28	53	62	75	82	62	55	42	36	564
Nizhnevartovsk	24	19	24	27	51	64	70	85	56	54	38	32	544

In summer the day length is 16-20 hours, whereas in winter it is 5-8 hours. The sunshine duration varies from 1300 hours (in the north) to 1900 hours (in the south). Annual number of dull days according to total cloud covers ranges from 130 to 160 days; the smallest number is marked in south-west of the region.

The yearly rainfall reaches 455-565 mm, the most of it falls in warm season. 80% of the annual rainfall precipitate during the period from April till October. High level of relative humidity (80% and higher) is marked during 100-140 days, mostly in the cold season. The smallest number of days with high relative humidity is in June-August.

The snow cover forms in October-beginning of November, and ablation starts at the end of April-middle of May. The number of days with snow cover varies from 180 (in the south) to 210 (in the north). The period from the latter half of November up to the beginning of January is the period of the most intensive growth of snow cover depth; it's the time when the rainfall amount increases due to high frequency of cyclonic weather. The water storage in snow reaches its maximum (160 mm and more) in north-east of the region, and its minimum (100 mm and less) in south-west.

Long-term data of wind pattern in the territory of KMAO is shown in the table 8.

Table 8. Annual frequency of winds of different directions, %.

Station	Direction								Calm
	N	NE	E	SE	S	SW	W	NW	
Surgut	11	8	12	9	10	18	21	11	10
Var'egan	13	10	7	13	16	17	12	12	11
Nizhnevartovsk	10	7	10	13	15	16	18	11	5
Ugut	14	6	5	10	19	23	9	14	15
Khanty-Mansiysk	9	8	11	11	16	23	10	12	9
Lar'yak	7	10	8	10	17	22	16	10	9
Lobchinskoe	10	7	10	13	15	16	18	11	5
Oktyabr'skoe	20	13	18	13	4	6	14	12	6
Kondinskoe	8	10	8	9	18	20	13	14	8

3.2.2 Hydrological regime of surface waters

Hydrographic network of KMAO refers to the Kara Sea basin. It includes a great number (19.6 thous.) of water passages, lakes, swamp lands, that is caused by the overmoistening of land, flat surface pattern and close occurrence of impervious horizons. Easy gradients of the land cause slow river flow and a high degree of sinuosity of the rivers. Big rivers have wide valleys with two-sided sharply meandering flood-plains. River channels abound in branches, creeks and lakes.

A weak drainage effect of the rivers is one of the most important factors of overmoistening and bogginess. The degree of bogginess of some gathering grounds is more than 50-70%. The best drainage conditions are to be found in the relatively narrow zone along the river-valleys. The main water arteries are the rivers Ob and Irtysh, the length of which within the region is 1165 and 244 km correspondingly.

3.2.3 Hydrological regime of the rivers

The greater part of the rivers of the region is snow-fed rivers. The percentage of snow, rain and phreatic recharge of rivers has its zonal peculiarities: in the north snow recharge prevails (60-80%), in the south rain and phreatic recharge.

Annual run-off is more than 300 mm in the north of the region, gradually decreasing southwards up to 100mm. In intra-annual flow distribution there are distinct periods of the spring flood, summer-autumn low-water, broken by rains and longstanding winter low-water. The feature of the local rivers (mostly of those, that run from south to north) is the beginning of the biggest outflow before the ice drift. The overflow duration in the medium rivers lasts for 2.5-3 months; it begins in the middle of April-beginning of May. The flood flow includes 45-70% of the amount of the annual run-off, 70-80% in the south. The minimal levels of run-off in the territory of KMAO are marked in the periods of summer-autumn and winter low-waters. The size of average long-term data of minimal summer-autumn overland run-off varies from 12 $l/s \cdot km^2$ to 1 $l/s \cdot km^2$.

Rain floods in KMAO take place almost every year. The amount of the total run-off of the biggest rain floods reaches 5-40%, sometimes up to 73% of the spring run-off. The changes of the rain run-off layer have zonal peculiarities, and it varies from 50 (in the south) to 125 (in the north).

The rivers in the northern part of the region freeze in the second decade of October, in the south – in the first decade of November. The average long-term data of ice thickness ranges from 113 to 140 sm. The maximum of ice thickness is marked in the end of March. In the northern parts of the region the duration of ice cover is more than 210 days, in the southern – less than 180 days.

3.2.4 Hydrological regime of the lakes

There are 2 peaks (in spring and autumn) and 2 falls (in winter and summer) of the annual level of small close paludal lakes. There is only 1 peak (in spring) and 1 fall (in winter) of the level of medium and large open paludal lakes. The small lakes freeze for long; not less than 200 days in the south, and not more than 240 days in the north. Large lakes freeze and ablate some days later than small ones; and their ice thickness is 15-35sm thicker.

3.2.5 Ground water

The upper hydrogeological layer includes aquifer systems dating back to Pliocene-Quarternary, Oligocene and Eocene epoch. The upper hydrogeological layer water is fresh; with salinity level of 1g/l. It is used for public and industrial water supply. The thickness of the layer is up to 300m.

The lower hydrogeological layer includes aquifer systems dating back to Aptian-Albian-Senomanian and Neocomian-Jurassic epoch. The ground waters are characterized by high salinity, high concentration of microelements, elevated temperatures and gas saturation. The ground water of Aptian-Albian-Senomanian aquifer system is widely used to maintain formation pressure during oil-field development.

Unconfined surface water plays the most significant role for the ecological processes, as well as water of Anthropogene, Neogene, Oligocene epoch, which are closely connected with surface water. Water is fresh with salinity level of 0.1-0.5 g/l, mostly calcium hydrocarbonated, rarely magnesium with leaching activity and weak carbon-dioxide aggressiveness.

3.2.6 Geology and soils

The sedimentary section includes Terrigenous Mesozoic and Cenozoic formations. The greater part of it is formed by the Mesozoic (Jurassic and Cretaceous) deposits, which have its links with all productive oil-and-gas bearing horizons and complexes of the region. They crop out to the daylight surface only in the Ural foothill belt, on the rest of the territory they are covered with Cenozoic deposits. Their power increases gradually from several meters to 2.5-3km; and the power of Cenozoic deposits – to 0.6-0.7 km.

On the surface of bedding rocks there are the deposits of Quarternary regolith.

In the deposits of the Upper Neopleistocene (the third and the forth terrace above flood-plain) limnetic and limnetic-alluvial sediments prevail. The deposits of the third terrace above flood-plain with the power of 20-25 m include channel sand and cobble-sand deposits, as well as flood-plain and limnetic-boggy sabulous-loamy deposits. In the valleys of the rivers Ob, Irtysh and other major rivers of the central and eastern parts of the region the fine-grained sand and sand clay prevail.

The second terrace above flood-plain is formed with argillaceous sands and flood-plain facies aleurites, which turn into the channel facies sands with megaclasts in the basal level downward the sedimentary section. The power of the accumulative part of the terrace reaches 15-20 m.

The first terrace above flood-plain is accumulative; it is formed by the sands, mostly fine-grained, rarely – argillaceous sands and aleurites. The basal level is well-defined; it includes consertal sands with occasional gravel, cobble and round stones.

The river-plains are formed with alluvium, the power of which reaches 20-25 m. The channel and river-plain facies of alluvium are represented by well-washed consertal sands and argillaceous sands, which turn into interlaid sand clay and loam soil. The basal level is formed with consertal sands with the slight infusion of megaclasts.

There are some factors that influence the process of soil formation. They are big amount of precipitation, low temperatures, considerable thickness and stability of snow cover, surface pattern that hampers the run-off of the surface and ground waters, variety of mother rocks (clay, loam soil, sands, cobble, and rocky grounds), permafrost. The overmoistening and gley-soil processes are the distinguishing features of the soil formation on the territory of KMAO.

The soils of the region are poor in nutrient substances; their features are strongly marked eluvial horizon, overoxidity, shallow humus horizon. The peculiarity of the soil mantle of the region is that the surface soil turns into peat. The boggy-peat and peat-gley soils are widely spread in the region. According to the character of watering, phytome and location they can be high-bog soil, low-bog soil and transitory soil.

High-bog soils are formed in the watershed divides and the upper terraces of the river-valleys; with the help of precipitation stagnant watering under the oligotrophic vegetations, which grow only if there is almost a complete absence of oxygen in water, extremely small number of nutrient substances and strong acidic reaction. High bogs are domed bogs; the maximum power of the peat bed is in the center of a bog. The most characteristic guide-plants are Sphagnum,Pinus sylvestris, Betula (Betula nana), Ledum, Cassandra, Rubus chamaemorus, Oxycoccus palustris, Scheuchzeria, Eriophorum vaginatum.

Soil profile:

horizon Оч. – the power is 10-15sm; sphagnous tirr made of necron of sphagnum moss and underground stems of dwarf semishrubs;

horizon T – peat horizon; according to the degree of decomposition they can be divided into 2 or 3 subhorizons;

horizon G – gley mineral horizon.

The depth that soil waters can reach in the warm season (30-60sm) is called the low limit of peat soil. Under it there are deposits of peat bioliths, which form soil.

The high-bog soil is overacidic (pH=2.5-3.8); peat ash content is low – 2.4-6.5%; the degree of decomposition is 20-25%; low density of soil (0.03-0.10); high moisture-holding capacity (700-1500%). Calcium, kalium and phosphorus content are low; base saturation is 10-50%.

The low-bog soils are formed in gashes of watershed plains, in the falls of river terraces; they are fed by mineralized ground waters. The phytome is eutrophic and mesotrophic: Carex sp, Phragmites sp, green hypnum moss; scrub growth − Alnus sp, Salix sp, Betula sp; tree crops − Picea obovata, Betula sp, Pinus sylvestris.

The low-bog soil profile:

T – peat horizon; according to the degree of decomposition, vegetations and marking they can be divided into subhorizons. The upper layer of profile is less decomposed, it is of brown color; and the lower layer of the peat is moldy, it has a dark-brown marking.

G – gley horizon; peat ash content is 6.5-12.0%, the degree of decomposition is 15-45%; weak or neutral acidic reaction. The base saturation and nutrient substances supply is better than that of the high-bog soils.

Transitory soils stand between the low-bog and high-bog soils according to the character of nourishment and vegetation. The low-bog soils are evolving through the stage of the transitory bogs into the high-bog soils.

According to the thickness of the organigenic layer all boggy soils can be divided into peat-like-gley (20-30 sm), peat-gley (30-50 sm) and peat (more than 50 sm). The latter is divided into peat soils in shallow peat (50-100 sm), peat soils in medium peat (100-200 sm) and peat soils in deep peat (more than 200 sm). According to the degree of decomposition in the upper layer (30-50 sm) all soils are divided into peat (less than 25%) and moldy-peat (25-45%). The complexes of boggy soils are widely spread. They are limnetic-paludal and hummock-ridge. There are active and inactive horizons in the paludal masses. The active horizon is the upper transitory layer of peat deposit up to the green cover. The thickness of the active layer is about 30-70sm. The rest of the peat deposit is the inactive horizon, which forms the very peat peposit.

3.2.7 Paludal life

The paludal ecosystems include hummock-ridge and limnetic-hummock-ridge complexes with dwarf shrubs and thin forest stand (Pinus sylvestris, Pinus sibirica, Betula sp.) along the hummock ridges and around the lakes; as well as grass-sphagnous communities in the lowest places. The moss cover is formed by sphagnum moss. The pine-shrub-sphagnum (the high) bogs are to be found on the watershed slightly hilly surfaces and flat-running surfaces of the central peat watersheds. The forest crop is very thin and is formed mainly by Pinus sylvestris with a slight infusion of Pinus sibirica. The shrub growth includes Betula nana, sometimes Salix lapponum and Salix myrtilloides. Chamaedaphne caliculata, Oxycoccus palustris, Andromeda polifolia prevail in the grass-semishrub corps.

The large paludal masses include compound limnetic-hummock-ridge complexes with the predomination of shrub-lichen-sphagnum communities on the slopes of peat lands and cotton-grass-sphagnous – in the falls. On the slopes of low peat banks there are Cassandra and Andromeda polifolium, sometimes Vaccinium vitis-idaea. On the tops of the ridges among shrubs there are Ledum sp, Betula nana, and single standing Chamaedaphne calculata.

The peat-sphagnous (transitory) bogs are to be found in valley-like peat falls, in the narrow winding small ravine with the slightly hillock pattern of surface, that is incised into the watershed slopes for 6-12m; as well as in the flood-plain-taiga zone, on the flat drainless minor river-plains. The forest crop is poor; the shrub growth is formed by Salix (S. lapponum, S. myrtilloides).

Comarum palustre, Carex (C. vesicaria, C. aquatilis, C. acuta), Menyanthes trifoliata, Cicuta virosa prevail in the grass-semishrub corps.

In the river-valleys and in strong-moisten near-terrace areas there are communities of Carex limosa, Carex diandra, Menyanthes trifoliata. The hypnum moss bog includes communities of dwarf arctic birches – yernics Betula (B. nana, B. fruticosa) with single standing Salix (S. rosmarinifolia, S. cinerea, rare S. lapponum).

The mammalian fauna of the bogs is poor; there are only 15-20 species, among them: Sorex (S. caecutiens, S. tundrensis). In the summer there are hoofed mammals – Alces alces, Rangifer tarandum in the open bogs. The umber of bird species in the high bogs can reach 120, because of birds that stop here during their spring flight. The reptiles are Vipera berus and Lacerta vivipara. The amphibias are Rana arvalis and Bufo bufo.

The wet lands are good for the development and habitation of numerous insects, especially Diptera (Simuliidae, Culicidae, Tabanoidae); as well as Odonata (Aeschnidae); Coleoptera (Carabidae, Chrisomelidae, Curculionidae, Sylphidae, Staphylinidae); Lepidoptera (Noctuidae, Sphingidae, Geometridae, Arctiidae, Licaenidae, Nymphalidae, Colias, Pieridae); Homoptera (Cicadidae, Cercopidae, Aphididae, Coccidae).

3.3 Remediation of oil-contaminated areas in KMAO-Ugra

3.3.1 Procedure and regulation

According to the governmental regulation of Russian Federation accidental oil spills are classified as the emergency situations. The companies, which have oil-production facilities and storage of oil, fuels and lubricants are obliged to elaborate the oil spill response plans. The accidental spill should be localized within 4 hours (ashore) or 6 hours (afloat) after the finding. In summer the afloat spills are localized by placing the red snake; and ashore spills – by diking of the site with imported or loose earth with the help of backfillers, bulldozer (banks and openings). Free oil is pumped out by the skimmer (the date is not subject to terms). In winter the oil spill response, especially in the bogs, is much easier: the diking is made with snow; if oil keeps fluidness – it is pumped out; if oil is frozen – it is gathered with the help of bulldozers or spades and is taken to the sludge tank. Within the oil field the oil traps (water seals) are placed at the confluence of small rivers and roads; it is done to prevent oil migration outside the oil field. The localization is carried out by the efforts of the special emergency rescue teams or the post-accident clean-up departments of the oil company. The main goal of the elimination stage is avoid the spread of oil outside the polluted area.

There are no laws and regulations for determining starting point and techniques of recultivation. Regulatory legal act set a recommendation for recultivation on the areas, which have a favorable conclusion from the State Ecological Expertise. However, starting from 1.01.2007 some amendments to Ecological Expertise Law came into force. It resolved that recultivation projects are outside legal framework and are not subject to ecological expertise.

Every single oil-polluted area is unique from the point of view of number of factors limiting biological decomposition of oil in soil; sometimes these factors can vary even within a certain area. That’s why it is very important to make a land conditioning before recultivation. It helps to get objective evaluation of its location, habitat confinedness, age, pollution rate and type, state of vegetation cover, soil and hydrographic features, number of litter, passability for machinery and other features necessary for determination of operation sections and execution order of recultivation at each of them.

On the basis of land conditioning data the recultivation project is elaborated (single or group); if a company has standard design of recultivation operations – working plan. In connection with the repeal of ecological expertise, it was decided to attract forestry agencies and regional environmental bodies to coordinate recultivation projects.

In recent years oil extraction and oil prices are increasing that's why oil companies bankroll rehabilitation of oil polluted lands; this statistics can be illustrated by the example of the Nizhnevartovsk region (fig. 4, 5).

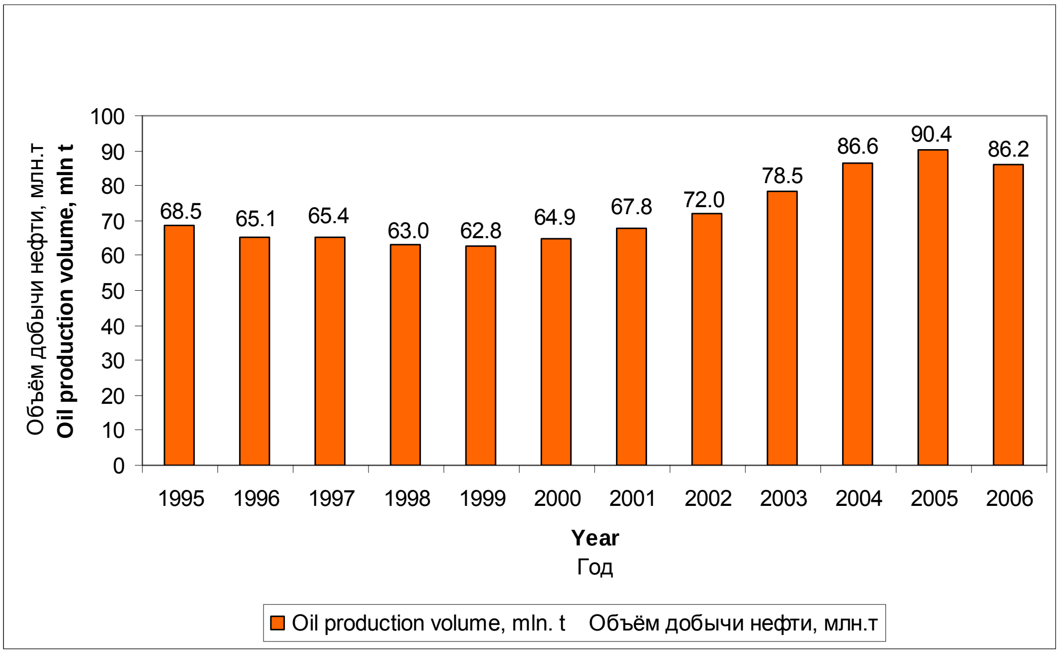


Figure 4. Dynamics of oil extraction in Nizhnevartovsk region.

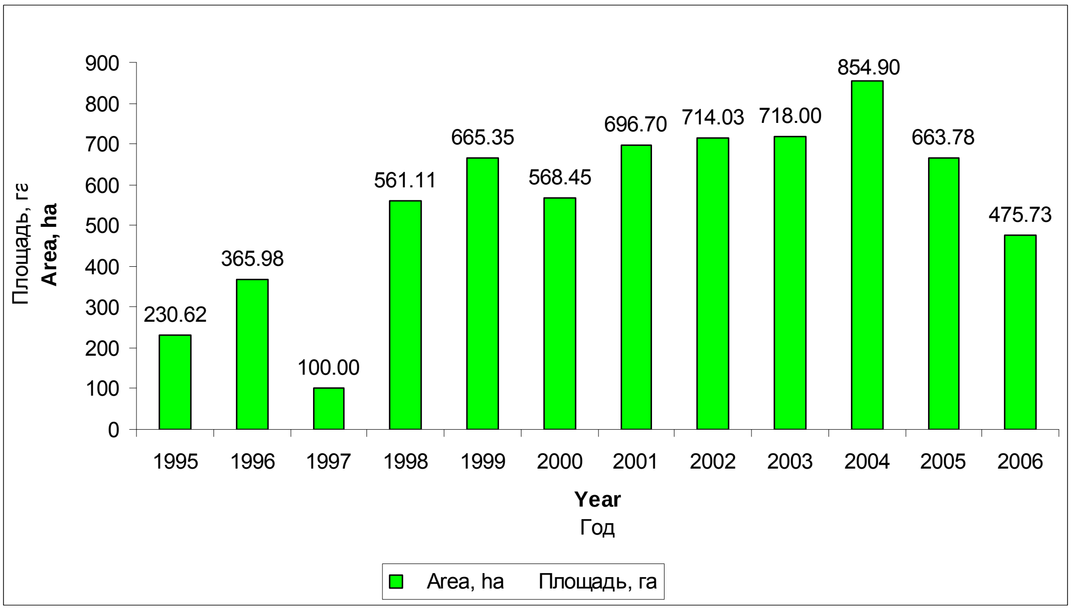


Figure 5. Recultivation of oil-contaminated areas in Nizhnevartovsk region.

The years 1990-1991 were marked as a so-called "ecological boom". It was the time of starting point of recultivation complex development in KMAO-Ugra. Late in 1991 the first Russian Environmental Law was applied. Exactly in that time the first domestic industrial biopreparation was tried. It was called 'Putidoil'. Concurrently development of local supervising ecological bodies took place.

The recultivation process quickly gained speed and methods of recultivation were elaborated. According to the official data, in 1994 the area of recultivated lands in KMAO reached 98.759 ha, in 1998 – 837.536 ha, in 2000 – 1013.192 ha.

There are great numbers of scientifically grounded methods of recultivation of oil-contaminated areas. For example, recultivation by ex situ method is widely used in developed countries in a case of minor spill. It means the complete removal of oil-contaminated top layer, its industrial purification and following return of fertile soil to the site. This method helps to rehabilitate damaged biocenosis in a short period of time.

In the KMAO-Ugra region the scale of contamination is huge, that is why the principal method here is in situ recultivation (rotary cultivation). This is the method of natural self-purification of surface biogenesis; it's based on such processes as evaporation, washout, destruction of oil under the influence of atmospheric oxygen, solar radiation, biodegradation and self-rehabilitation of biocenosis. The main goals of recultivation are acceleration of natural self-purification of soils, maximum mobilization of inner sources for rehabilitation of its functions. It can be achieved with the help of agronomic and agrochemical operations.

It's important for the recultivation process to reach the permissible level of oil concentration in soil so that development, growth and reproduction of main components of soil and surface biocenosis are possible as well as formation of dense vegetation cover.

Reasons for application of this method are to be found in guidance for recultivation, elaborated by Tyumen forestry station and published in 2000 in the Tyumen State University.

However, it's hard to say that the original biotope disturbed by oil spill is rehabilitated everywhere. To be more precise the main goal of recultivation process was reached only in some single sites, while the main principle – do not harm– is ignored almost everywhere. This situation is caused by the usage of recultivation methods elaborated for mineral soils of midland zone of Russia (i.e. soil for agricultural utilization).

3.3.2 Guidelines for oil-contaminated lands

It should be noted that regulatory system for assessment of oil contaminations in KMAO-Ugra and in Russia itself is weak. To assess ecological risks it is necessary to have strict standards for oil and oil products content in soil. What's more these standards must be differentiated with respect to surface pattern of the polluted land, its status and the age of the oil spill. Scientific findings are numerous but they are uncoordinated and sometimes contradictory. All that makes it impossible to use these findings as objective criteria for ecological risks assessment.

In the early 90s law currently in force was Guidelines for exposure of degraded and polluted lands, damage assessment system for chemical-polluted lands. It fixed strict norms for the soil pollution rate: oil and oil products limits – less than MPC (maximum permissible concentration) (MPC for oil in soil have not been defined yet; MPC for petrol, some benzene hydrocarbons (benzene, cumene, styrene, toluene) are 0.1 – 0.5 mg/kg of soil), low pollution – 1-2 g/kg of soil, medium pollution – 2-3 g/kg of soil, strong pollution – 3-5 g/kg of soil, heavy pollution – 5 g/kg of soil. In practice these norms are strict above measure. According to the regulations of recultivated lands acceptance (in KMAO-Ugra 1994-2002) MPC for oil in mineral soil was equal to 20 g/kg of air dry soil, MPC for oil in peat – 80g/kg. In accordance with current regulations for land conservation retirement (approved by governmental resolution № 830, 2.10.2002) areas where MPC reaches figures above are subject to conservation retirement that in practice is invalid.

In 2004 the Government of KMAO-Ugra approved the regional norms “Permissible oil and oil products residues after recultivation and rehabilitation of land in KMAO-Ugra” which differentiated MPC of oil with the respect of functions of areas, types of soils and its features (table 9).

Table 9. Maximum permissible concentration of oil and oil products.

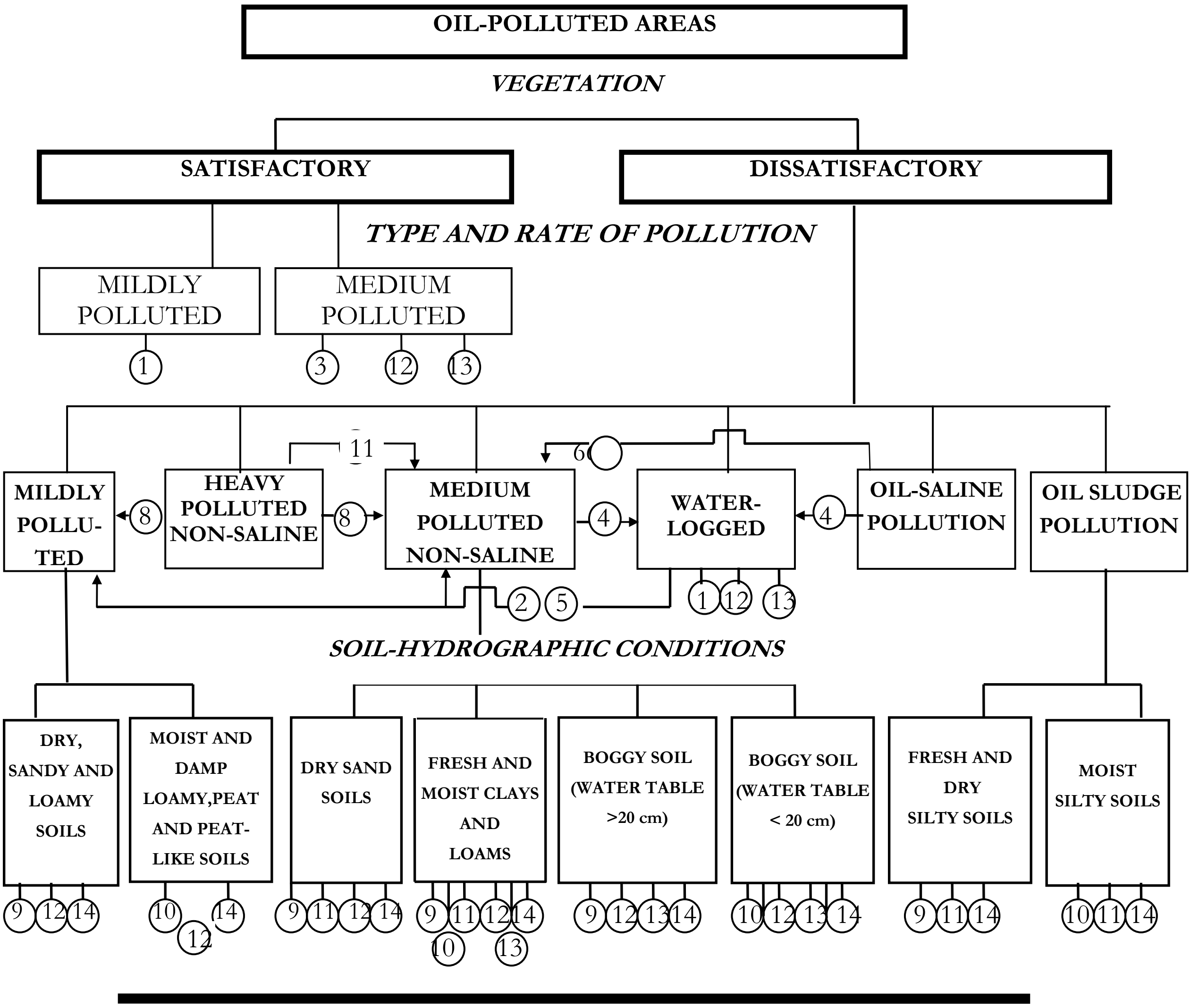
Forest utilization			
Soils		***Soil horizons***	***Standard value, g/kg***
Texture	***Type***		
Sand, sandy loam	Soddy-podzolic, podzolic	A0, A1	15
		Ae, Bf, Bh, B, C	3
Light loam	Alluvial swamp slimy-peat	Ad, T	10
		A, G	2
Loams, clays	Soddy-podzolic, podzolic, swamp-podzolic, gley soils, low differentiated taiga soils	A0, T, TA	30
		A, A2g, Ae, B, C	5
-	Highbog peat	TA, T1 (Оч)	60 (100*)
		T	30
	Transitory bog peat, low-land bog peat	T	20
Water utilization (including drinking water supply protective area, fishery water bodies)			
All textures	All types	A0, T, TA	5 (or up to the level of regional background matter)
		A, Ae, B,C	1 (or up to the level of regional background matter)
Agricultural utilization (plough lands, fields, meadows, posture lands and other)			
Lightloams, sandy loam	Soddy-podzolic, podzolic, alluvial soddy-meadow, swamp slimy-peat	Ad, A1, T, TA	5
		A, B, G	1
Constructional utilization			
Sand, sandy loam	-	-	5

*Permissible residues of petroleum hydrocarbons at the rate of 100 g/kg is for those parts of bog with present vegetation cover, peat density not more than 0.07 g/cm³ (sphagnous tirr, , undecomposed peat in places of zero mechanic effect) and projective cover of grass and shrubs not less than 30% form natural one only.

It’s necessary to take into consideration such features of oil-polluted area as soil, hydrographic and weather conditions, because the major number of hydrocarbons decomposes by microorganisms operating effectively at the temperature of 20-25°C, good airing and moisture conditions.

The climate of the region is extremely continental, with long and inclement winters, wanton springs, brief summers and short autumns (see above). There are some factors that influence the process of soil formation. They are big amount of precipitation, low temperatures, considerable thickness and stability of snow cover, surface pattern that hampers the run-off of the surface and ground waters, variety of mother rocks (clay, loam soil, sands, cobble, and rocky grounds), permafrost. The overmoistening and gley-soil processes are the distinguishing features of the soil formation on the territory of KMAO. The soils of the region are poor in nutrient substances; their features are strongly marked eluvial horizon, overoxidity, shallow humus horizon. The peculiarity of the soil mantle of the region is that the surface soil turns into peat.

Thus, soil and weather conditions of the region are extremely severe for the process of oil biodegradation. Soil overmoistening on the one hand hampers deep penetration of oil, but on the other hand it complicates recultivation from the point of technical and agrobiological operations. On the basis of soil-hydrographic and weather conditions of KMAO B.E. Chizhov and V.A. Dolinger elaborated classification of oil-polluted areas in taiga zone of Western Siberia (fig.6).



1 TERMS

- VEGETATION

  SATISFACTORY -

Grass and moss cover > 50%, or number of vigorous trees >350 units/ha or good low cover > 5 thous. units/ha.

- **HEAVY POLLUTED SOILS -**

Oil concentration in a layer (0-10 cm) > 40% (peat) and > 20% (sand, loam) or total oil concentration in soil profile > 20 kg/m²

- **MILDLY POLLUTED SOILS -**

Oil concentration in peat < 4kg/m², in loams and sand < 8 kg/ m²

- **MEDIUM POLLUTED SOILS**

Have medium indexes between heavy polluted soils and mildly polluted soils

- **SALINE SOILS -**

RECULTIVATION RECOMMENDATIONS

1. Natural cleaning up of soils and reservoirs from oil pollution
2. Gathering of free oil
3. Usage of methods of natural vegetation preservation

4. Diking for localization of oil spills or water-logged area to drive oil from soil
5. Drainage of water-logged and overmoisted areas
6. Natural soil desalination

7. Removal of dead wood and litter
8. Removal of heavy polluted top layer of soil
9. Soil tillage (depth 15-30 cm)
10. Soil tillage and micro-landscape formation

11. Peat and fertilizer treatment
12. Lime and artificial fertilizer treatment
13. Oil-oxidizing microorganisms treatment
14. Planting of meliorates

Figure 6. Classification of oil-polluted areas for recultivation.

The given classification is of a prompting format, as the official one (in particular according to the contamination rate) doesn't exist. Developers, who elaborate projects of recultivation, finish off the given classification with regard to local conditions, changes in normative standards of recultivation, own views and abilities of equipment application.

There is an additional classification (table 10) that covers such information as limiting factors of biological degradation of oil, main negative effects on the process of natural decomposition of oil and recommendations concerning measures against limiting factors. This is the gist of recultivation techniques conducted in KMAO-Ugra. It should be mentioned that these techniques demand rough impact on the recultivation area – washout of the area, repeated rotary cultivation, micro-landscape creation, heavy artificial fertilizer and deoxidizer treatment.

Table 10. Limiting factors of biological oil degradation and measures against them

Limiting factors	**Negative effects on the process of natural decomposition of oil**	**Recommendations**
Oil film > 5mm, bituminous oil cover on the soil surface	Aerating decrease, acidulation of subsurface layers, non-applicability for renewal by seeds	Gathering and removal of free oil with the help of sorbets. Clearing up of over-moisted soils with the help of water jet. Oil film destruction with the help of soil tillage.
High hydrocarbon concentration in top layers: > 20 % (in podzolic-gley soils), > 40 % (in peat soils)	Vital functions reduction of soil microflora and mesofauna. Bad physical soil properties: increase in hydropathy of sandy soils, decrease in permeability of loamy soils, aerating decrease, acidulation. Non-applicability for higher plants	Removal of heavy polluted top layer of peat soils Peat placement into mineral soils and its following interfusing with polluted subsoil. Rotary cultivation of oil-contaminated surface layer of peat soils for its interfusing with less contaminated layers (not more than 30cm). Regular soil tillage by rotary cultivation
Excessive lentic over-moistening of boggy soils	Oxygen starvation, high acidity, unfavorable temperature regime of soils	Regular soil tillage by rotary cultivation. Micro-landscape formation. Planting of hydrophilic meliorates
Insufficient moistening of sandy and sabulous soils	Vital functions reduction of oil-oxidizing microorganisms, hampered renewal by seeds	Peat placement into soils and its following interfusing with polluted subsoil, sprinkling irrigation.
High acidity of soil	Vital functions reduction of oil-oxidizing microorganisms.	Dolomitic meal or limestone meal or other deoxidizer treatment. Aeration improvement by regular tillage or micro-landscape formation in over-moisten areas
Chloride-sulfate salination of soils	Vital functions reduction of oil-oxidizing microflora, non-applicability for wooded and grass plants.	Natural desalination of soils (dumping etc.).
Siltage of soils	Aerating decrease, salination of soils + contamination	Peat placement into soils and its following interfusing with polluted subsoil. Regular soil tillage by rotary cultivation.
Accumulation of intermediate oil decomposition products	Acidulation of soil with organic acids	Dolomitic meal or limestone meal or other deoxidizer treatment. Planting of grass-meliorates
Lack of available forms of K, N, P in soil	Vital functions reduction of oil-oxidizing microorganisms, depressed development of meliorates	Phosphate, nitrogen, potash or combined fertilizer treatment
Lack of oil-oxidizing microorganisms in soil	Slow oil biodegradation	Placement of native microbal culture or industrial microbiologic specimen


Figure 7. Cleaning of peatland.


Figure 8. Rotary cultivation of oil-contaminated bogs.


Figure 9. Phytorecultivation.

3.3.3 Current knowledge of environmental impact by applied remediation techniques

To perfect the process of recultivation it is significant to take into consideration not only quantitative parameters written in the certificate of the site but qualitative changes in soil, hydrographic and weather conditions which will accompany toxic components degradation.

Oil in soil may be in the following states:

- liquid, mobile state in free, water-emulsive phase of soil pores;
- free, fixed state in soil pores and cracks by way of cement between soil particles and devices;
- occluded state connected with organic or mineral-organic mass;
- solid layer on the surface.

In a case of oil spills, high-molecular oil fractions and intermediate degradation products create kirrs (decomposition-resistant skins) on the surface; whereas in a case of repeated spills of mainly heavy oil – hard asphaltic coats. Resinuous-asphaltic components sorb mainly in top layers of soil that lead to cementation of soil, deterioration of water-air features, swamping and change of oxidation-reduction conditions. Thus oil and oil-products pollution of soil leads to irreversible changes of structural, physical, physicochemical and microbiological properties of soil. It means a considerable reorganization of soil profile that decreases its fertility and agricultural utilization.

Oil in soil involves violation of water-air regime since it fills soil space and adhere soil fines turning them into bituminous shell. As a rule, topsoils suffer most from oil spill; it changes its texture into heavy, it changes its density into strong, and it changes its color into dark. Soil reach in oil loses ability to absorb and keep moisture due to processes of oil components drive of subsurface air and the process of hydrophobic film formation around soil particles. The most severe consequences are marked at the complete coverage of soil with oil film. In that case, soils lose ability to absorb and keep moisture; its infiltration of water and moisture-holding capacity is less than those of its background countertype. Besides moisture level of upper layer decreases; moisture level of subsurface layer increases, moisture transpiration through highly hydrophobic soil layers is hampered. Some researchers found out that violation of water and nutrients entry, oxygen starvation are the main reasons for inhibition of growth and demise of phytocenosis in oil-contaminated areas.

Since oil ingresses in soil, it starts fractionating. The process of natural oil degradation depends on 3 principal interdependent factors: physical, chemical and microbiological. It's impossible to treat each factor separately; it can be done only from the point of predominance of them at certain stages of oil degradation. Physical processes lead to evaporation of light ends, to washout and spreading of amount of hydrocarbons (it should be noted that it is not self-purification, because it pollutes adjacent landscape components). Chemical processes produce water-soluble components, asphaltic-resinous components and insoluble components (i.e. bituminous components turn into its insoluble state and humify). This process is irreversible; in 10 years after pollution its activity decreases, in 25 – bituminous components are noticeably devastated.

According to the data from exploratory grounds of Geomicrobiology Lab on the basis of the Institute of Biology (the Academy of Sciences of the USSR), oil residual in soil in 1 year after pollution was: central taiga zone – 40.7- 44.4%; southern taiga zone – 12.5%; wooded steppe zone – 4.4% (dry meadow) and 1.65% (moist meadow); subtropical zone – 0.47%. It's obvious that the speed of soil self-purification increases from north to south.

It was defined that within one climatic zone and the same contamination rate (24 l/m^2) oil residual content in soil decreases quicker if moisture rate is higher. The main chemical process of oil degradation is oil oxidation in aerobic conditions that occur in two directions. On the one hand, it's mineralization, which simplifies oil structure; one the other hand – condensation, which enriches oil with asphaltic-resinous polar compounds.

By radial distribution of oil in soil profile so-called "barrier- accumulators" (layers with high oil capacity) play significant role. Accumulator-layers of oil components are high capable organic layers of soil and peat (organo-sorption) and layers of light texture that have highly effective soil space and low capacity (mineral-sorption). Thus, peat layers and peat soils possess the highest oil capacity and form thick barrier-accumulators in vertical soil profile. The number of pollutants assembling in accumulator-layers depends not only on oil capacity of layers but on their depth. For example, peat soils with depth of more than 10 cm assemble the majority of oil and hamper its spreading to ground waters. It is also known that oil capacity of soil depends on moisture rate of peat. Peat soil with relative moisture of about 50% keeps 350 l of liquid oil/m²; whereas air-dried peat can keep up to 600 l/m². Oil capacity of loose top soil is higher if to compare with deep solid layers of decomposed soil.

This data helps to define exact area of oil-contaminated peat soils, and their ability to keep oil and oil-products within can be helpful in major oil spills prevention. Thus it's necessary to use dried peat to prevent oil spreading, as it absorbs oil-products perfectly.

Oil properties (its chemical composition, viscosity, presence of concurrent mineralized edge waters) determine character of its fractioning. In a case of surface oil spill its vertical penetration in soil creates chromatographic effect leading to differentiating of oil fractures. High-molecular oil components with high content of asphaltic-resinous and cycle compounds assemble in the top humic layer; and low-molecular components with high level of water solubility assemble in deep layers as well as edge waters.

On the first days of pollution oil represses biological activity of microorganisms despite of their big number.

The research of aliphatic hydrocarbons oxidation set the following features:

- alcanes are assimilated by most microorganisms – yeasts, microscopical filamentous fungi and bacteria – alcanes are the only nutrient source for them;
- alcanes of light oil ends with short carbon chain (less than C_9) are not assimilated due to toxicity level, but they can oxidize; longer carbon chains increase oxidation yield, while speed of oxidation drops;
- saturated hydrocarbons (oil alcanes) degrade quicker than unsaturated ones;
- branched-chain compounds (isoalcanes) oxidize slower than straight-chain hydrocarbons (n-alcanes).

For light and heavy oil fractions biodegradation speed varies. Light oil-products (diesel fuel) with starting concentration of 0.5% degrade from 10 to 90% during 1.5 months (depending on volatile hydrocarbon content). Solid paraffin is slowly degraded and oxidized; it can stay in soil pores for a long time. It leads to violation of moisture and air exchange. Cycle hydrocarbons with saturated bond oxidize very hard.

Influences of light and heavy oil fractions on living organisms are quite different. Light fractions affect them immediately after the contact, while heavy fractions effect takes time. Acute toxic effect upon plants is displayed by highly volatile oil fractions, whereas violations of water-air soil regime are caused by liquid hydrocarbons.

According to our rehabilitation observations of oil-contaminated areas (including areas after traditional recultivation), domination of piny-suffrutescent-sphagnous communities was substituted by cotton-grass-sphagnous (sedgy) ones in 5, 12, 21 years after the accidental oil spill.

Practically, almost the same combination of plants is responsible for self-rehabilitation of contaminated areas in forests and marshlands. Even in 20 years after oil spill the total projective cover degree of bogs was 1.7 times less (with grass and suffrutescent) and 2.5 times less (with moss and lichen) than that of non-contaminated areas; biodiversity index (Shannon's diversity index) was 2.1 times smaller.

During self-rehabilitation of marshes oil content reduction in peat goes slower than that of mineral forest soils (correlation indexes between age of spill 0.22 and 0.65 respectively). It has positive impact on the grass-and-suffrutescent cover rehabilitation (correlation index – 0.95), but it has weak influence on moss and lichen recovery (correlation index – 0.55).

Observations of the oil-contaminated part of upland bog, which was recultivated according to the traditional techniques (i.e. rotary cultivation of peat bed) established following results: in 2 years after recultivation the total projective grass cover of the area was 13.7 times worse than that of non-contaminated areas; there were no moss and lichen. In 7 years – the total projective grass cover of the area was 5.2 times worse; the total projective moss-and-lichen cover – 53.4 times worse than that of non-contaminated areas. Grass diversity in the recultivated part of bog was 2.5-3.2 times poorer; this area was marked with complete change of species composition, where plants tolerant to anaerobic conditions prevailed.

Microbiocenosis study showed that oil contamination decreases respiration rate of boggy and forest soils greatly; it can be proved by the fact that population of microorganisms, fungi and native species is reducing. Soil pollution modifies oxidation-reduction potential in the direction of reduction; the number of anaerobic microorganisms grows. Soil state after oil spills remains unfavorable over the period of 20 years both for marsh and forest soils, but the process of rehabilitation of soil boicenisis goes slower in marshes.

Application of traditional techniques of recultivation stimulates forest mineral soil recovery due to improved aerobic conditions of soil; however it hardly works with boggy soil mainly because of its high anaerobic degree (fig 10-12).

Figure 10. Non-oil-contaminated upland sphagnous-suffrutescent bog.


Figure 11. Part of upland sphagnous-suffrutescent bog in 3 years after recultivation.


Figure 12. The same part of upland sphagnous-suffrutescent bog in 8 years after recultivation.

Comparison of two oil-contaminated areas (one – after traditional recultivation and the other – without any), show that rehabilitation of biocenosis is better without recultivation, provided that there are good conditions for self-recovery created (oil film or asphaltic cover are removed to restore air exchange).

The appraisal of recultivation guidelines for KMAO-Ugra made by telmatologists on the order of SibNIPIRP set following conclusions:

1. The practical guideline “Recultivation of oil-contaminated lands of KMAO” does not include rationales for techniques of oil-contaminated peat bogs recultivation, does not meet the requirements of environment protection, environmental engineering, does not correspond with environmental impact assessment and violate the Environmental Law (art. 43 of Federal Law “On Protection of Environment”, 2002; art. 3 of Federal Law “On Ecological Expertise”, 1995; section II, III of “Assessment of Economical Impact on Environment”, 2000; section 6 of “Ecological substantiation instruction of economical or other activities”, 1995).

2. The practical guideline allows for use of extremely rough methods of processing and use of heavy machinery, in spite of the fact that it contradicts local and foreign standards. What is more it makes it impossible to reach the goal – rehabilitation of local peat bog vegetation.

3. Application of the prescribed methods to the peat bogs (especially watered ones) would worsen ecological state of the site, so the effect from such activity falls outside the limits.

According to telmatologists, rotary cultivation (up to 25 cm) of the bog surface leads to destruction of active layer of peat deposit (i.e. herbs, root habitable layer), to microflora failure and in depth penetration of contamination. Besides, from the point of chemical and physical features of peat, rotary cultivation of undrained, watered, slightly decomposed peat layers cannot improve water-air regime of the upper peat layer. Peat moisture is energy bounded; transference of the peat into three-phase condition needs drying-out of peat bed. Practically, rotary cultivation is connected with creation of drainage systems, which radically modify natural conditions of the recultivated area. Mechanical equipment in its turn is the source of additional impact on the soil.

As it was said, rotary cultivation destructs active layer of peat deposit, where mass- and energy interchange takes place. This active layer formed from subshrubs roots and mossy tirr is able to swell when is moistened and to compress when is drained. Due to this ability roots of plants can touch low more moistened layers of peat deposit. After the impact of rotary cultivation and heavy mechanical equipment the top layer actually loses ability of self-recovery of water-air regime. As a result, the top layer became weather-dependant (in a case of vast rainfall – the area is flooded; otherwise – fast drainage); in other words such contrasting water-air regime negatively influences on the growth of plant-meliorates.

Observation of the earlier recultivated territory held by the experts of Moscow state university in 2006 proved negative influence of rotary cultivation while recultivating marshlands. It was marked that the pace of rehabilitation was higher in the areas, where natural water-air conditions were safe, where there wasn’t complete rotary cultivation and where local vegetation despite of the quantity still existed.

Moisture level of oligotrophic peat bogs was from 66.9 points (upland part of oligotrophic mid-hummock-ridge bog complex) to 97.7 points (cattail marsh). Maximum relative changes of moisture content are respectively: in the direction of decrease of index – about 22%; in the direction of increase – 12%. It should be noted that minimum of moisture level turned out to be smaller even than values, characteristic of xeromorphic habitat of the region – lichen pine forest (which are 69.5%). Reasons for such evident decrease of moisture level of biocenosis are connected with rough mechanical impact of heavy equipment during recultivation. This leads (in a case of rotary cultivation) to violation of peat masses integrity, lowering of water-holding capacity and rapid outflow of water from homogenized peat stratum into low layers. Unfavorable water regime in its turn causes reduction of plants tolerance to oil pollution.

Rotary cultivation results in rise of strongly acidic sterile peat, non-applicable for vegetation; as well as in travel of oil-contaminated peat from active layer into anaerobic conditions. In the most difficult areas (where recultivation result is negative), correlation between total projective cover of the area and composition and quality indexes of plants and soils is extremely small. Overall negative situation in such areas is displayed in deregulation of interrelations of soil components which are responsible for external impact resistance. The feedback of total projective cover and peat index (r=-0.53, p=0.80, n=10). Peat index depends on the great amount of mineral fertilizer, injected into oil-contaminated areas of oligotrophic peat bogs, as prescribed by regional standards. The major negative effect comes from surface injection of phosphorous fertilizers, which are weak water-soluble. As a result, toxic phosphorous concentration accumulates in the upper layer of peat deposit, whereas root layers lack of phosphorus. It's obvious that fertilizer and lime treatment in oil-polluted heavily saline peat soils leads only to deterioration, as it increases osmotic pressure of soil solution, which is responsible for drying out of plants and inhibition of microflora development. Negative impact is also marked by the recommended deoxidizing soil treatment; correlation indexes between pH of water and saline extracts and total projective cover degree in the areas with dense vegetation cover are positive and equal to +0,65-0+0,63 (significant from p=0,90 for n=10). It's natural, since acid reaction if favorable for boggy plant species. That's why injection of magnesium and calcium carbonate during recultivation is considered to be pointless. Recultivation operations are to be aimed at removal of oil pollution, washout of easy-soluble salts from peat and recreation of natural water-air regime.

The experts of Moscow state university believe that character of plants transformation and modification of ecological conditions in oligotrophic marshes testify violations of hydrological and nutrient balance. These violations lead to significant diversification of the ways to re-from biocenosis. Besides it leads to intensification of secondary factors and features against deterioration of boggy homeostatic mechanism. If the progressive succession passes good, secondary meadows and eutrophic bogs are formed on the recultivated surfaces, as well as strange for initial biocenosis species

The main difference between oil pollution and any other anthropogenic impacts lays in its full influence on the environment and its rapid response. Assessment of after-effects of such pollution doesn't show if the ecosystem is stable or it's continuing to degrade. In every operation concerning oil spill response or rehabilitation of polluted lands the main principle must be observed – do not do more harm than it's been already done.

The whole process of recultivation should be based on this principle. Maximum mobilization of inner resources of the ecosystem for rehabilitation of its initial functions – is the main matter of the principle. Self-recovery of ecosystem and recultivation is a constant biochemical process. Recultivation is the continuation (acceleration) of natural purification process, in current use of which climatic, microbiological and landscape-geophysical natural resources.

Today in KMAO-Ugra every recommended technique and even its operations contradict basic principles of environment engineering, approaches by natural analogy, balance state and conformity. Natural analogy approach means usage of those recultivation techniques that reproduce natural activity of ecosystem components. Balance approach includes appropriateness of economic activity to resource and ecological abilities of ecosystems. Conformity approach makes it necessary to observe controllable ecosystems and control them in accordance with situation. Recommended recultivation techniques cannot reproduce natural activity, don't take resource and ecological abilities of peat marshes into account

Boggy cenosis is a quite complicated self-organizing system; its functions have been forming for centuries. Characteristic features of a separate peat stratum vary depending on the depth of occurrence. The upper layer of peat deposit is full of roots of trees, shrubs, grass which form a firm frame responsible for carrying capacity of bogs. Peat deposits are rich in microorganisms, but radical drop in their number (from 10 cm) is the characteristic feature of Siberian peat boggy soils. In soil layers (further than 30 cm) the number of bacteria and actinomycetes is just 1% from their number in top layer. Rotary cultivation destroys existing structure of the peat deposit, hampers ulmification and delays boggy boicenosis self-recovery for years.

All marsh plants have common features: they are perennial, they have long mature ramulous rootstocks, they are adapted to poor gravity ventilation of substrate, and they are characterized mainly by vegetative propagation and subsurface location of overwintering parts with renewal buds. Thus, rotary cultivation causing plant destruction is irrelevant; it leads to much more negative consequences than initial oil pollution, especially in oligotrophic peat bogs. It was already mentioned that it violates art.43 of Federal Law "On Protection of Environment". It's also should be noted that rotary cultivation results in penetration of pollutant into subsurface peat stratum, in microflora destruction and retardation of oil destruction.

Recultivation of oil-contaminated marshes should be based on protective techniques, which do not ruin major bioproductive peat stratum. The offered method (covering of oil-polluted bogs with bio- and sorption-active particulate peat) can be referred to them; moreover it has passed a certain level of approbation.

Laboratory trial of mulching of oil-contaminated peat deposit with dry milled peat showed reduction of boggy toxic load more than half due to sorption ability of mulch (table 11).

Table 11. Oil redistribution after milled peat mulching (laboratory trial).

Oil volume injected into sample (percentage of dry peat weight), %	**Relative oil concentration in layers, %**	
	Milled peat	**Peat deposit**
1	17.8	82.2
3	32.5	67.5
5	49.3	50.7

Peat is an active biosystem, possessing great number of microorganisms, which can oxidize hydrocarbon material. As it has pores, milled peat contains major amount of air. According to literature, air capacity of milled peat equals to 515-2300% per unit volume of solid substance. Air fills big pores in particles and around them. Thus, this active biosystem contains significant amount of oxidizing agent.

Injected bio- and sorption-active layer extracts half of the amount of pollutant from contaminated active peat stratum. That consequently leads to growth of destruction activity of the system: active peat stratum – oil – milled peat in general (table 12). Besides, active bioproductive layer of peat deposit gets rid of half technogenic load and restores its ability to produce vegetation.

Table 12. Dynamics of oil biodegradation in peat deposit.

Experiment	**Oil volume injected into sample (percentage of dry peat weight), %**	**Oil degradation rate, %**	
		In 50 days	**In 95 days**
No recultivation	1	12.3	30.1
	3	31.3	38.9
	5	38.1	39.8
Mulching by milled peat	1	35.3	44.8
	3	39.1	42.6
	5	31.0	37.2
Mulching by milled peat + NPK	1	44.3	54.3
	3	36.6	43.8
	5	39.9	42.1

Experts of SibNIPIRP placed several fixed experimental grounds in the territory of hummock-ridge peat marsh (with water table of 10-15 cm) (fig. 13-14) for the purpose of comparison of different recultivation techniques. The investigation lasted for the period of 2005-2007.

Figure 13. Experimental ground for recultivation techniques. Method of rotary cultivation (in 3 years after the oil spill).

Figure 14. Experimental ground for recultivation techniques. Method of peat placement (in 3 years after the oil spill).

In particular, two method of recultivation were under study. They are: traditional methods demanding rotary cultivation of peat deposit and sparing method elaborated by our institute, which include peat placement. In a case of a normalized oil pollution (10 l/m²) in a checkground general amount of oil concentrated in the layer of 5-10 cm. By rotary cultivation oil penetrated the whole layer of processed soil (up to 40 cm); whereas by peat placement oil penetrated no further than that of checkground (5-10 cm), but under 15-20 cm of dry milled peat. This fact contributes to the sorption of light oil components, which are easily evaporated in checkgrounds (table 13).

Table 13. Comparison of oil concentration in peat soils of check and experimental grounds over 2005-2006 by different methods of recultivation (percentage of oil from dry peat, %).

Experiment	**Date of tests on oil concentration in peat**		
	26.09.2005	**29.05.2006**	**13.07.2006**
No recultivation	11.1	10.9	7.9
Rotary cultivation	15.8	10.8	10.9
Peat placement: a)milled peat b)peat deposit	 6.4 6.9	 1.9 6.4	 0.5 3.6

After oil spill aboveground parts of local vegetations died in all experimental grounds. However after the process of peat placement, oil concentration in the zone of perennial's reproductive organs was lower than phytotoxity level due to sorption capacity of milled peat. That's why these areas have been marked for active regrowth of plants in autumn (table 14).

Table 14. Rehabilitation of local vegetation in check and experimental grounds over 2005-2006.

Experiment	**Date of tests**			
	26.09.05		**2.10.06**	
	Number per m²	**Air-dry weight, g/m²**	**Number per m²**	**Air-dry weight g/m²**
No recultivation	-	-	672	36
Rotary cultivation	-	-	-	-
Peat placement	31	89	496	69

In a year after milled peat placement local perennial vegetation appeared everywhere, as well as sprouts of marsh plants; rehabilitation of boggy biocenosis in the check grounds began by the second half of summer.

Intense oil biodegradation in milled peat and vast masses of plants are due to more favorable conditions for microorganisms activity and development of plants (table 15).

Table 15. Microorganism population in peat samples from check and experimental grounds, CFUx10^6

Experiment	**Hydrocarbon oxidixing**	**Using mineral forms of nitrogen**
No recultivation	1.04	2.29
Rotary cultivation	5.74	3.44
Peat placement: a)milled peat b)peat deposit	 22.06 0.95	 12.12 0.31

The number of microorganisms in milled peat layer exceeds that of peat in check grounds and in areas undergone rotary cultivation; however microorganism population in peat deposit itself is lower than that of peat in check grounds. There is every reason to believe that after milled peat mulching, the main body of oil degrades exactly in that mulching layer; while oil degradation is continuing, pollutant is moving from milled peat layer and peat deposit.

Thus, application of recultivation operations for oil-contaminated marsh ecosystem is inadmissible, if it brings destruction of bioproductive active peat layer; as it hampers the process of ulmification, accelerates organic-matter degradation in peat, intensifies pollutant penetration into low anaerobic strata and preserves contaminant for a long period. It also violates biosphere functions of bogs, while bog system is a part of the "lungs" of the Earth.

In the system: peat deposit – oil – milled peat decomposition activity of contaminant isn't reducing, but instead is intensifying by means of usage of milled peat biodestructive facilities. Self-recovery of marsh biocenosis goes prompt, peat deposit biocenosis remains undisturbed.

High water table, distinctive feature of marsh systems of KMAO-Ugra, hampers deep penetration of oil into low peat strata. Main amount of hydrocarbons are to be found in peat stratum of 5-10 cm; oil penetration rate for moisty peat is lower than that of dry mineral soil. Experts of SibNIPIRP carried out a number of researches on upland bog with water table of 5-15 cm. this study showed that in a month after oil spill 92% of oil concentrated in mossy frill; oil products concentration in the upper layer (5 cm) didn't exceed 3.5%. This implies that prompt removal of oil (during a month after the failure) from mossy frill by means of cleaning and squeezing makes it possible to omit many of traditional rehabilitation operations and use only phytoremediation of peatland.

Today phytorecultivation means seeding of perennial meadow grass; for the acceptance of the recultivated area it is necessary to present full-fledged sprouts of perennials and even oat. It should be underlined that phytremediation finishes oil removal stage of recultivation, but the final stage of the whole process brings rehabilitation of the disturbed biogeocenosis. Thus, with an eye to biocenosis rehabilitation planting of hillocks and rootstems of palludal vegetations is more preferable than that of meadow grass despite of their poor appearance.

However, it doesn't mean that planting of annual and perennial grass is of no use for the areas under recultivation. In recent years phytoremediation (i.e. rehabilitation of polluted soils with the help of plants) is considered to be the most promising method of recultivation in Western Europe, the USA and Canada. There are certain species of plant tolerant to certain types of pollutants, which are planted after technical treatment of soil. It is done for them to absorb and deactivate a part of contaminant, to stimulate biodestruction activity with the help of root exudations. Artificial systems of soil and water cleanup are formed by the analogy of natural system with the help of simple technical equipment, selection of remediating plants and competent use of agrochemicals.

3.3.4 Sorbents used for the oil contaminated marsh lands

The offered recultivation technique for oil-polluted marshlands involves usage of air-dried milled peat (milled peat with density of 0.1-0.4 g/cm^3 and moisture level of 40-60%) that is in fact appears to be peat sorbent. Air-dried peat applied to oil-polluted section of peat deposit is a poriferous system with air (oxidizing agent) capacity of 515-2300% per unit of solid substance. It contains sufficient number of microorganisms, including seeds of native vegetation, which can oxidize hydrocarbon material.

The layer of air-dried peat sorbs up to 50% of oil, left after surface pumping (oil residual concentration in peat should not exceed 15 l/m^2). As a result it eases active peat stratum and creates favorable conditions for its self-recovery. Boggy biocenosis renewed on the surface of clean peat intensifies decomposition of oil residuals. Table 16 shows comparative analysis of home- and foreign- origin sorbents.

Table 16. Comparative analysis of sorbents.

Sorbent	Price of 1 kg USD	Recycling	Packing, kg	Absorption time, kg/kg	Water reclamation, %	Thermal endurance at 300°C	Sorptive features, kg of oil per kg of sorbent
TurboSorb, France	5.8	incineration	plastic sack	*	*	not resistant	3.6
STRG, Russia	10-15	regeneration, incineration, pressing	plastic sack with feedstock	10 sec	99.5	resistant	50
Primesorb, USA	25	regeneration, incineration	plastic sack	5 min	99.5	resistant	27
Lessorb, Russia	3	pressing, incineration	plastic sack, 5-15 kg	30 min	*	resistant up to 200 °C	5
Sorboil, Russia	2	pressing, incineration	plastic sack 501, container 1 t	30-60 sec	*	resistant up to 2000 °C	8
BTK-1 Russia	7	incineration	sack 15 kg	*	*	*	11

On testing of recultivation techniques we used the best Russian sorbent STRG (thermally-split graphic) to evaluate qualities of milled peat in comparison with sorbents used for oil spill elimination. STRG sorbent is meant for localization and elimination of oil spills upon the water and soil surfaces. It is the hydrophobic one, being a powder material of 100-percent floatability, having bulk density of 4 – 12 kg/m^3 and sorptive capacity of 40-60 kg of oil and oil products per kg of sorbent. Maximum density of saturated STRG sorbent does not exceed 700 kg/m^3. STRG sorbent of graphite at the site of oil spill can be produced with help of mobile plant U-STRG, which productivity is 30-60 kg/h and 3-5 kg/h.

STRG sorbent has a range of advantages over milled peat: higher capacity for oil, hydrophobicity, rough oil retention. However it has negative impact on oil decomposition process in a case when sorbent remains on the surface of recultivated area. Our experiments proved that oil biodegradation in milled peat began in the first field season after recultivation, while oil biodegradation after recultivation with the use of STRG sorbent – in the third season.

3.3.5 Needed improvements according to Russian partners

The advent of regional norms is the step forward despite of the fact that these standards work mainly for new oil spills, whereas there are a lot of old (>2 years after the incident) spills. It's not a secret that in 2 months after the incident light oil (with boiling-point over 100°C) disappears; in 2-3 years – oil components with boiling-point over 300°C; only heavy low-toxic components (paraffine, asphaltene, resins) remain. Our findings (table 17) show that water extracts from peat samples taken from spills aged 1-2 years stimulated oat growth, and only when there was high concentration of chlorides in soil oat growth was inhibited.

Table 17. Phytotoxicity of water extracts from peat samples taken from spills aged 1-2 years.

Toxicant content in peat		**Phytotoxicity of water extracts for oat**	
Oil, %	**Chlorides, mg/kg**	**Germinative capacity, %**	**Sprout length, mm**
0	0	19.0	12.2
0.6	398	26.7	20.8
13.3	842	24.0	18.8
21.0	855	26.3	16.7
25.1	3868	11.3	13.6
25.9	58	23.3	16.7
45.1	1334	25.0	17.6

It's necessary to find more differentiated approach to each contaminated territory to reduce ecological risks. Particularly, fractional composition of oil residuals in soil and spill location should be taken into consideration. At the present moment it's impossible because certified assessment methods deal with cumulative oil concentration (gravimetry, spectrometry). The method of gas chromatography helps to define fractional composition of oil residuals, but this method is certified for water samples only. That's why it's urgent to certify the method of gas chromatography for definition of fractional composition of oil traces in soil samples and to conduct heavy fractions toxicity research. It should be done to prove amendments to normative regulations of oil MPC after recultivation according to the fractional composition.

It's also important to reconsider principal mythological approaches for the definition of oil content in peat. Peat soils are quite different structurally and functionally from mineral ones. Peat soil is a multiphase polydisperse system. Peat soil in undrained state contains 95% of moisture. Current assessment method means drying out of peat soils. When amount of moisture in peat soils reaches 30-50% (instead of natural 95%) and in mineral soils – 10-15% sample mass becomes 12 times lesser, peat soil changes its structure and dispersiveness. For these reasons, the results do not show the real picture of marsh lands contamination. As far as peat soils are concerned, oil concentration should be assessed in natural conditions of moisture rate and undisturbed structure. Knowing that total error of calculations by oil content assessment is about 25-45% it's reasonable to use express methods in situ (project of Moscow state university).

It's also important to consider following:

1. By useful properties recovery of peat bed we mean:
   - primary phytocenosis recovery ;
   - rehabilitation of ulmification.

Special acceptance criteria should be worked out for oil contaminated peat bogs different from oil contaminated mineral soils.

2. Maximum permissible concentration of petroleum hydrocarbons in peat should be equal to oil capacity of peat (that is mass of oil that peat can absorb and keep per unit volume). In this case oil residual in soil is the maximum permissible, excluding opportunities of oil and oil products traveling to the adjacent areas. Oil capacity should be stated in mass unit of oil per unit volume of peat (e.g. 1 kg of oil/1 m^3 of peat). Thus physical nature of absorption and keeping of pollutant in the whole volume of polydisperse system (i.e. peat) should be taken into consideration.

There is no normative standard for chloride tolerance in Russian Federation. There is no research works on consequences of saline contamination for marsh land biocenosis; no cases of recultivation of salinized marshes; there is no experimental database for saline regulation and determination of ecological risks.

To sum up the results of ecological assessment of recultivation techniques applicable for oil-contaminated oligotrophic peat bogs, it should be said that today the main goal of oil-polluted lands recultivation is reduction of oil concentration in soil up to the level of normative regulations. It is usually done by means of excessive negative impact on ecosystem unequal to real damage rate of biocenosis. Thus, the main principle of recultivation – rehabilitation of damaged biocenosis remains unobtainable.

There is no unique recultivation method suitable for every soil and weather conditions. That's why it is important to elaborate complex techniques and operations of recultivation, that is able to take into account all features of every oil-contaminated area and thus making rehabilitation of damaged biocenosis faster.

Inefficient monitoring system controlling polluted and recultivated areas aggravates ecological risks. Oil companies are to furnish monthly accounts to national and regional inspection bodies, which should include number of failures, accidental spillage volumes and area of pollution. These oil-contaminated areas are under examination of inspectors, but vast territory of oil fields and lack of inspection body personnel make it impossible to carry out thorough examination of an oil field and those polluted parts which haven't been reported about by companies owning them. From time to time unscheduled inspections of oil fields are carried out, sometimes information of oil spills is arrived through “hot line”, and however discovery of concealed oil spills is a kind of lottery.

From 1994 to 2002 there were rules of recultivated areas accepting procedure in the region. They were elaborated in time of recultivation system development, so it is obvious that they had a number of shortcomings, nevertheless it was a united document regulating acceptance of lands. Today there are no such rules, we have to follow regional standards for permissible oil concentration in soils; though actually it controls only oil content. Before 2007 there was a regional committee appointed by the region administration to accept recultivated lands. Besides Forestry Department and Department of Environment Protection form their own committees. That's why without common rules of acceptance procedure there is room for subjective evaluation of recultivation quality.

There is no regular monitoring of recultivated lands in the region, excluding selective examination of previously-accepted areas by inspecting bodies' experts. In recent years the vast majority of oil producing companies pays much attention to oil spill prevention. They realize examination, defectoscopy and anticorrosive treatment of field pipelines, their reconstruction; they use pipes with advanced corrosive resistance and improve system of failure detection and reporting. However governmental control demands only elaboration of preventive and oil spill response plans; as well as its expertise. In other words, they simply state number of emergency procedures instead of analyze its sufficiency for failure risks minimizing. It's more economically reasonable for oil companies to eliminate oil spill effects than to replace hazardous parts of pipeline system.

4 Common remediation techniques for oil contamination in soil and groundwater

4.1 Remediation techniques

A database survey of common remediation techniques for oil contaminated soil has been performed in the project and is described and summarized in the section below. A full version of the remediation technologies is given in appendix 1a and b. The information is mainly taken from the "Federal Remediation Technology Roundtable (FRTR)" (homepage: http://www.frtr.gov) and from Faisal et al, 2004.

Remediation techniques for soil contaminated by oil can be divided into in-situ (treatment of the soil without moving) and ex-situ (treatment of the soil on another site). Oil in soil and/or groundwater can be degraded by micro organisms (e.g., fungi, bacteria, and other microbes) in the soil and most of both in-situ and ex-situ techniques involve the stimulation of biodegrading processes. In the presence of sufficient oxygen (aerobic conditions), micro organisms will ultimately convert many organic contaminants to carbon dioxide, water, and microbial cell mass. In the absence of oxygen (anaerobic conditions), the contaminants will be ultimately metabolized to methane. Sometimes contaminants may not be completely degraded, but only transformed to intermediate products that may be less, equally, or more hazardous than the original contaminant. By injection of air into soil and/or groundwater biodegradation is enhanced and light hydrocarbons are also volatilized and can be removed from the soil by vacuum extraction. The most common techniques are described very shortly below and more in detail in appendix 1 a and b.

Bioventing, airsparging, soil vapor extraction, bioslurping and ground water pumping, thermal treatment and phytoremediation all are examples of techniques that can be used in-situ.

Bioventing injects air into unsaturated or vadose zone of the soil at a rate that maximizes biodegradation and minimizes off-gasing of volatilised contaminants into the atmosphere.

Air sparging injects atmospheric air into the saturated zone (groundwater) to volatilise groundwater contaminants and to promote biodegradation. The injected air volatilises the contaminants in the flow channels and transports them to the vadose zone where they are either biodegraded or removed by the **soil vapor extraction** system. Horizontal wells can be drilled where necessary i.e under buildings etc when contaminants are not accessible through vertical drilling.

Biosparging is like airsparging but the difference is that both air and nutrients are injected into the soil and into groundwater.

Bioslurping is a kind of combination between bioventing and soilvapor extraction. Free product and contaminated groundwater are pumped up and separated as wells as the vapors are separated between liquids and vapor.

Thermal treatment is an in-situ technique where steam is forced into an aquifer through injection wells to vaporize volatile and semi-volatile contaminants. Vaporized components rise to the unsaturated zone where they are removed by vacuum extraction and then treated.

Groundwater pumping is a technique where groundwater is pumped up and treated before it is reinfiltrated or discharged into a surface water body. The groundwater that is pumped up can be treated with various different techniques. When the groundwater is pumped the groundwater surface is also lowered around the well and this is utilized to prevent spreading of contaminants to clean groundwater downstream.

Phytoremediation uses plants to clean up contaminated soils. This process advantages the ability of plants to take up, accumulate and or degrade constituents that are present in soil and water environments.

Soil washing uses liquids (usually water, sometimes combined with solvents) and mechanical processes to scrub soils from contaminants. The soil washing process separates fine soil like silt and clay that hydrocarbons tend to bind and sorb onto, from coarser soil-particles like sand and gravel.

Solidification/stabilisation reduces the mobility of hazardous substances by converting the contaminant in a less soluble, immobile and less toxic form. Most stabilisation/solidification processes have limited effectiveness against organics and pesticides.

Reactive barriers rely on the natural movement of water to carry the contaminants through a underground wall-system where the contaminants are either trapped or transformed into harmless substances when passing the reactive material.

Monitored natural attenuation is an approach that focuses on control and verification that natural degrading processes of contaminants are going on without spreading and disturbing the natural environment. Before natural attenuation can be proposed fro a site, soil and groundwater samples must be taken and analysed to document that natural attenuation is occurring and to estimate the effectiveness of natural degrading processes over time for the studied site.

Landfarming, biopiles/ composting, bioslurry, thermal desorption, constructed wetlands are all examples of techniques that can be used ex.-situ.

Biopiles or composting is a technique where microbial activity is stimulated by aeration and addition of minerals, nutrients and moisture in piles of petroleum contaminated soil. These piles are usually covered to prevent runoff, evaporation and volatilization and to promote solar heating.

Landfarming is an above ground remediation technology that usually involves the spreading of excavated contaminated soils in a thin layer on the ground surface of a treatment site and stimulating aerobic microbial activity within the soil through aeration and/or the addition of nutrients, minerals and water/moisture (Faisal et al, 2004).

Bioslurry requires excavation of the soil and mixing with water and other additives to form a slurry. The slurry is treated in a controlled reactor where biodegradation occurs in a rapid rate.

Thermal desorption is a technology where contaminated soil is excavated, screened and heated to release petroleum from the soil. It involves heating soils to temperatures of 100-600 ºC so that those contaminants with boiling points in this range will vaporize and separate from the soil. The vaporized contaminants are then collected and treated by other means (Faisal et al, 2004).

Constructed wetlands are most commonly used for waste water treatment for controlling organic matter and nutrients and to trap suspended sediments. The wetland is controlled by both aerobic and anaerobic processes where plants and microbes degrade the contaminants in the passing water.

4.2 Sorbents used for oil spills

Sorbents are often used to collect oil spills in surface waters. Sorbents are insoluble materials or mixtures of materials used to recover liquids through the mechanism of absorption, or adsorption, or both. Absorbents are materials that pick up and retain liquid distributed throughout its molecular structure causing the solid to swell (50 percent or more). The absorbent must be at least 70 percent insoluble in excess fluid. Adsorbents are insoluble materials that are coated by a liquid on its surface, including pores and capillaries, without the solid swelling more than 50 percent in excess liquid. To be useful in combating oil spills, sorbents need to be both oleophilic (oil-attracting) and hydrophobic (water-repellent).

Sorbents can be divided into three basic categories: natural organic, natural inorganic, and synthetic.

Natural organic sorbents include peat moss, straw, hay, sawdust, ground corncobs, feathers, and other readily available carbon-based products. Organic sorbents can adsorb between 3 and 15 times their weight in oil, but there are disadvantages to their use. Some organic sorbents tend to adsorb water as well as oil, causing the sorbents to sink. Many organic sorbents are loose particles such as sawdust, and are difficult to collect after they are spread on the water. These problems can be counterbalanced by adding flotation devices, such as empty drums attached to sorbent bales of hay, to overcome the sinking issue, and wrapping loose particles in mesh to aid in collection.

Natural inorganic sorbents consist of clay, perlite, vermiculite, glass wool, sand, or volcanic ash. They can adsorb from 4 to 20 times their weight in oil. Inorganic sorbents, like organic sorbents, are inexpensive and readily available in large quantities. These types of sorbents are not used on the water's surface.

Synthetic sorbents include man-made materials that are similar to plastics, such as polyurethane, polyethylene, and polypropylene and are designed to adsorb liquids onto their surfaces (like a sponge). Other synthetic sorbents include cross-linked polymers and rubber materials, which absorb liquids into their solid structure, causing the sorbent material to swell. Most synthetic sorbents can absorb up 70 times their own weight in oil.

The characteristics of both sorbents and oil types must be considered when choosing sorbents for cleaning up oil spills:

- Rate of absorption -- The absorption of oil is faster with lighter oil products. Once absorbed the oil cannot be re-released. Effective with light hydrocarbons (e.g., gasoline, diesel fuel, benzene).
- Rate of adsorption -- The thicker oils adhere to the surface of the adsorbent more effectively.
- Oil retention -- The weight of recovered oil can cause a sorbent structure to sag and deform, and when it is lifted out of the water, it can release oil that is trapped in its pores.

Lighter, less viscous oil is lost through the pores more easily than are heavier, more viscous oils during recovery of adsorbent materials causing secondary contamination.

- Ease of application -- Sorbents may be applied to spills manually or mechanically, using blowers or fans. Many natural organic sorbents that exist as loose materials, such as clay and vermiculite, are dusty, difficult to apply in windy conditions, and potentially hazardous if inhaled.
- Organic sorbents are normally used for oil spill outdoors when it is difficult to recollect the used sorbents. Synthetic sorbents are normally used as mats or booms, and they are collected after use for destruction. Inorganic sorbents are used mainly indoors in industries and outdoors on streets by the rescue services teams.

It is today very difficult to get a good overveiw of the sorbent market. The producer use different methods to show that just thier product is the best one. That makes it very har for a consumer to choose the best one for his needs. For example the producers show that sorbents can absorb oil up to 50 times their own weight. But if we compare the absorption capacity by volume sorbent it turns out that the capacity of the products on the market is about 0,4 to 1,0 kg by volume sorbent. It is therfore important to ask the producers for comparable data before choosing a spcific sorbent.

Applicability:
Although they may be used as the sole cleanup method in small spills, sorbents are most often used to remove final traces of oil, or in areas that cannot be reached by skimmers.

Limitations:
Sorbent materials used to recover oil must be treated in accordance with approved regulations. Any oil that is removed from sorbent materials must also be properly disposed of or recycled.

5 International research and networks

The majority of oil spills (number of events) in the world occur in coastal waters or in ports consequently leading to that most of the oil spill cleanup and remediation efforts have focused on marine environments. Thus, the accessible literature of gathered information and experience around oil spills is mainly focusing of marine conditions and warmer climates than the conditions found in the Khanty Mansiysk region. The area comprises one of the largest wetland areas in the world experiencing very cold winters and fairly warm and short summers. Furthermore, it is not only oil spills that can cause damage to the wetland areas but also highly saline groundwater from the low levels of oil exploration depth. If leakage occurs the highly saline groundwater reaches the freshwater environment changing the chemistry of the water and the conditions for the freshwater species.

Of the worlds oil producing countries there are a few with similar climate that can be found in KMAO; Alaska, Norway and some parts of USA. These countries experience cold climate but none of them has such huge wetland areas as in KMAO. Consequently, it is hard to find experiences from oil exploration sites around the world that can be directly applied to the Khanty Mansiysk region. Despite this, there is a lot of relevant information that could contribute to a development of a strategy for oil contaminated sites in KMAO.

The project has carried out a literature search, mainly via Scopus abstract and citation database. Oil in combinations with remediation/bioremediation and wet land/marsh were scanned. Just a few references out of hundreds were chosen. Selection was based upon time of publication (late articles were preferred), language (English was preferred and German accepted) and to find a few articles for each remediation technique. None of the articles were directly applicable to the unique situation in Khanty-Mansiysk. The literature study is attached in appendix 2.

Also, other literature and research works have been found through internet based search. The most relevant for the project are mentioned in the text below:

- A Norwegian study presents results from field tests and discusses permafrost response to environmental and industrial loads performed at Norwegian Geotechnical Institute (NGI) during the years 1999 to 2003. The study focuses on the knowledge of the potential of the Arctic ecosystems to degrade and tolerate hydrocarbon spills. Bioremediation of hydrocarbons, which is a technique frequently used in warmer regions, was studied at four arctic field sites and degradation processes were measured and evaluated in cold climate. The study is very relevant regarding the degradation of oil during wintertime in Khanty Mansiysk. It is shown that micro organisms are active at temperatures down to -20ºC and that it is the access to water (unfrozen water in frozen soil) that regulates the activity. The thaw-depth response to oils pills is also discussed in this work (NGI, SIP, 2003). The report can be downloaded at: http://www.ngi.no/staticpages/sip7/front.htm#Introduction.

- The Alaska Department of Environmental Conservation (ADEC) has statutory responsibility for preventing air, land, and water pollution. ADEC regulates oil and gas activities, such as the disposal of drilling mud and cuttings, the flaring of hydrocarbon gases, and the discharge of wastewater. ADEC provids a huge amount of information about prevention and response of oils pills in Alaska by the Division of Spill prevention and response (SPAR). Specific information of oil spills to tundra and the recommended treatment is summarized in a manual that can be downloaded from the tundra treatment webpage http://www.dec.state.ak.us/spar/perp/r_d/ttman/tt_man.htm

  At the end of the "Tundra treatment manual" a reference list of very relevant articles for oil spills in cold climate can be found.

  Alaska Department of Natural Resources Division (ADNR), through the Division of Oil & Gas (DO&G), Division of Mining, Land and Water (DMLW), the Office of Habitat Management and Permitting (OHMP), and the Office of Project Management and Permitting (OPMP), reviews, coordinates, conditions, and approves plans of operation or development and other permits as required before on-site activities of oil exploration can take place. In the publication "Preliminary Best Interest Finding 2008 Proposed North Slope Areawide Oil and Gas Lease Sale (April 19, 2007)" chapter 6 is treating "Specific Issues Relating to Oil and Gas Exploration, Development, Production and Transportation" with valuable information about prevention and remediation of oil spills from exploration and transportation of oil in Alaska. The publication can be downloaded at http://www.dog.dnr.state.ak.us/oil/products/publications/northslope/nsaw08-ff_toc.html

- An article by **John H. Vandermeulen and Cal W. Ross** 2004 with title: *Oil spill response in freshwater: Assessment of the impact of cleanup as a management tool*
  Abstract: A wide variety of cleanup methods has been used following oil spillage in freshwater environments, but in few cases has there been rigorous follow-up assessment of the possible environmental impact of these methods *per se*. Where impact of cleanup has been considered, it was largely in the context of effectiveness of oil removal, and rarely to determine any negative environmental impact that the cleanup itself might have. A review of a number of documented oil spill incidents in freshwater environments revealed the

following. (1) follow-up monitoring of spill cleanup has not been seen as a formal or integral part of the cleanup procedure, nor as a regular part of either federal or local governmental spill response. (2) spill response in the freshwater environment has been guided largely by knowledge gained from marine spill response, and from other environmental fields, despite significant differences between freshwater and marine conditions. (3) cleanup activities do cause environmental impacts, over and above the impact of the oiling. These include impacts on regrowth of shoreline vegetation, entrainment and enhanced persistence of oil into river and marsh sediments, long-term oiling of creek and river beds resulting from certain methodologies, and impacts from disposal of oiled soils. (4) the "no-action" (i.e. self-clean) option does not appear as a formal response in freshwater spill situations, although there are situations where no cleanup may be considered a valid response option (for example, lightly oiled wetlands). (5) "habitat rarity", as a separate factor in determining spill response, has had little discussion or application.

- Another article (Reynolds et al, 1997) present a comparative study between the degradation of heavy oil and diesel in soils treated either by landfarming or in bioventing. The study focuses on petroleum releases in cold, remote regions. The conclusion of the study is that landfarming can be a reasonable alternative to bioventing for both heavy-oil and diesel contaminated soil at remote sites typical of cold regions.

- Torre Jorgensson and Michael Joyce (1999) describes the consequences of the remaining gravel roads and pads, gravel pits and overburden stockpiles, drilling reserve pits, occasional accidental spills, and other minor disturbances to the tundra, left by the oil industry in Alaska. This range of disturbed lands will eventually require rehabilitation. The article describes six general strategies, incorporating a variety of land rehabilitation techniques, that are applicable to the range of disturbed conditions resulting from oil development in arctic Alaska. These strategies include: 1) flooding of gravel mine sites for fish habitat, 2) creation of wetlands in ponds perched on overburden stockpiles, 3) revegetation of thick gravel fill and overburden to compensate for lost wildlife habitat, 4) removal of gravel fill to help restore wet tundra habitats, 5) restoration of tundra on less severely modified habitats, and 6) remediation of areas contaminated by oil spills, seawater spills, and drilling mud. These strategies are intended to create habitats that are useful to a diversity of plants, invertebrates, birds, and mammals. The general goals of each strategy, as well as results of experiments evaluating various techniques applicable to each strategy, are reviewed.

- One paper with study area in Khanty Mansiysk region was found (Hese and Schmullius). The paper presents first results of the OSCaR pilot study for terrestrial oil spill classification with very high resolution Earth observation data and object oriented image processing methods. The developed class hierarchy for a test area in the Khanty Mansiysk district classified oil spills using spectral information, object shape information and class related features. Final accuracy assessment has not been performed for this study yet but the preliminary results show that class related information can be applied successfully to utilise the structural image object information.

- A long term study of a small flood plain wetland located in Pequannock River in New Jersey which was contaminated by oil seeping out of the ground, show that a carefully supervised cleanup followed by a scientifically driven monitoring program can be effective in removing oil from a sensitive wetland habitat. The source of the oil was from a pipeline that transported oil from the oil fields in western New York State to Bayonne at the turn of the century. The pipeline was abandoned in the 1920's and removed, leaving behind subsurface deposits of spilled oil that contaminated the adjacent wetland during periods of elevated groundwater. Six to eight inches of the native soil horizon was removed as part of the oil spill cleanup effort thereby denuding the wetland. The Revegetation/Restoration commenced with the placement of hemp mat to minimize erosion as all of the stream side vegetation was removed during the cleanup operation followed by the emplacement of coir logs along the stream edge. In the spring of 1999, plantings of potted native shrubs and forbes were installed. A monitoring program for determining the success of the revegetation/restoration effort was set up. Species composition and productivity measurements were an integral part of the parameters to measure the progress of the effort to determine comparability between the remediated site and undisturbed wetlands. More information about the project can be found at: http://clu-in.org/conf/tio/ecorestoration3_121406/

- An experimental petroleum spill was staged in a marsh on the St. Lawrence River to learn more about the behaviour and biological effects of oil in freshwater marshes and to test and develop new counteractive methods for use in these fragile habitats. The goal of the project was to determine the natural recovery rate of the habitat through the breakdown of hydrocarbons by native plants and bacteria and to test the effect of certain treatments and procedures on this natural recovery process. Within the first 21 weeks of the experiment, natural physical processes such as dilution by tides and currents removed approximately 10-15 per cent of the oil spilled in the marsh. Specialized instruments showed that bacteria adapted naturally to break down the oil—their populations increasing dramatically while there was oil present, and decreasing after it was gone. The addition of agricultural fertilizers did not enhance the degradation rates of oil, however it did stimulate plant growth significantly, and reduce toxicity at a faster rate than in untreated plots. Although there was no fertilizer applied the second year, accelerated plant growth was observed in the treated plots the following two summers. The fact that these aquatic plants appear to store fertilizer as nitrogen in their roots means that minimal treatments have long-term effects on habitat recovery. The findings will be used to develop a suite of new techniques for determining when sites are considered sufficiently free of contamination, as well as new protocols for dealing with oil spills that threaten wetland habitats on the St. Lawrence River. More info can be found at: http://www.ec.gc.ca/envirozine/english/issues/22/feature3_e.cfm

- The US Environmental protection Agency (EPA) offer important information and research about oil spills mainly focusing on oil spills to the sea. Nevertheless, much of the information regarding prevention of spills and contingency planning could possibly be applied to oil spills in the Khanty Mansiysk region. Of special interest is the report “Guidelines for the bioremediation of marine shorelines and freshwater wetlands” that demonstrates that, if significant penetration of oil takes place into the subsurface of freshwater wetlands, biodegradation would take place very slowly and ineffectively. This is because of the anaerobic conditions that quickly occur in these types of saturated environments, and anaerobic biodegradation of petroleum oils is much slower and less complete than under aerobic conditions. The report (and other guidelines and research) could be downloaded at: http://www.epa.gov/oilspill/index.htm

There are several European networks that could contribute with relevant information regarding spills of petroleum to soil and wetlands and remediation technologies of contaminated soil in general. Some of them are mentioned below:

NICOLE is a leading forum on contaminated land management in Europe, promoting co-operation between industry, academia and service providers on the development and application of sustainable technologies. NICOLE's objectives are to:

- Provide a European forum for the dissemination and exchange of knowledge and ideas about contaminated land arising from industrial and commercial activities;

- Identify research needs and promote collaborative research that will enable European industry to identify, assess and manage contaminated sites more efficiently and cost-effectively; and

- Collaborate with other international networks inside and outside Europe and encompass the views of a wide a range of interest groups and stakeholders (for example, land developers, local/regional regulators and the insurance/financial investment community).

More information about NICOLE, organisation, members and publications can be found at www.nicole.org

CLARINET has been a Concerted Action within the Environment & Climate Programme of the European Commission DG Research, and is co-ordinated by the Austrian Environment Agency. The action was finished in 2001. Working fields of Clarinet have been:
- Sustainable Management of Contaminated Land
- Brownfields and Redevelopment of Urban Areas
- Remediation of Contaminated Land Technology Implementation in Europe
- Review of Decision Support Tools for Contaminated Land Management, and their Use in Europe
- An Analysis of National and EU RTD Programmes related to Sustainable Land and Groundwater Management
- Proceedings of the Conference on "Sustainable Management of Contaminated Land"
- Variation in calculated human exposure. Comparison of calculations with seven European human exposure models
- Special Edition on Land Contamination and Reclamation: The Sustainable Management and Remediation of Contaminated Land

Clarinet has been the starting point for several activities, of which some have been taken up by the NICOLE network. An example is the Risk Assessment Comparison Study (short: Eurorisk, 2004). In this study a number of risk assessment methods in Europe have been compared. A conclusion has been that main differences occur from how different parameters are chosen. In some countries larger safety factors are applied for these parameters, which in the sum can result in significant differences for the risk assessment.

EURORISK is a European-wide approach for the development, deployment and operation of new information services for risk management. EURORISK is a consortium of 60 partners across 15 nations, steered by EumetNet, comprising national civil defence organisations. It is a European scale approach for developing, delivering and operationally exploiting new information services for the management of Natural and Industrial Risks to enhance security of peoples and goods. It comprises:

- All types of Risks : atmospheric, geophysical , industrial
- All phases of the risks cycle : prevention, early warning, crisis, recovery
- New services for the operational actors of the risk chain : Civil Protection Units, Land planning
- entities, early warning operators, local authorities,…
- Addressing major European needs at local and global scales , adapted to the operational national practises/ ways to proceed
- From observed data (in-situ,EO, Airborne,) up to final information entering in the end-users decisional systems

The network has a focus on remote-sensing technologies.

EURODEMO is a European Co-ordination Action for Demonstration of Efficient Soil and Groundwater Remedation. It is about to be finished. Eurodemo established a database on demonstration projects for soil and groundwater remediation at http://www.eurodemo.eugris.info/ . So far the registered demonstration projects do not address situations that are found in the Khanty-Mansiysk region.

EUGRIS

EUGRIS is a web portal offering information and services on topics related to soil and water at http://www.eugris.info/. The information can be put directly onto the web by members and is not reviewed. EUGRIS operates as a community of collaborating projects, people and organisations who co-operate to supply information for the benefit of everyone and also to promote themselves and disseminate their work.

6 Identification of knowledge gaps and needed improvements

During the seminar in Stockholm in November the Russian partner thoroughly described the current situation with the petroleum contaminated soil that is a result of the many oil spills in the region of Khanty Mansiysk, and identified knowledge gaps as presented in the above section 3. The consortium discussed the Swedish risk assessment model and guideline values for contaminated soils used in Sweden. It was clear that to correctly assess the risk of leaching oil in the Khanty Mansiysk region a better risk assessment model is necessary. Improvements of the classification of the sensitivity of the different land types are needed, as well as adaptation of guideline values for different soil types/soil use. The guideline values also need revision regarding fractionation of the components of oil (i.e. intervals of alifates and aromates) and the soils ability to sorb oil (peat is an excellent sorbent). Standardisation of analytical methods for detection and fractionation of oil in peat soil is an important task to gain comparable results and guidelines.

More research and exchange of knowledge is needed regarding the degradation of oil and the toxicity of oil in wetland areas. The nature in Khanty Mansiysk is unique and hydrologic regimes are vital for the survival of the ecosystems in the region. The currently used remediation technique of landfarming helps to degrade the oil but it destroys the function of wetlands and it affects the hydrologic regime. A risk assessment tool for the area needs to be able to weight the effects of different remediation techniques on ecotoxicity as well as hydrology and groundwater. A risk

assessment tool also needs to predict the consequences of remediation in a long term perspective. More, the risk assessment tool should also consider the combined effects of oil and high salinity water into freshwater systems.
The most important task to fulfil that can help the future situation of oil spills in the region is to find a cost effective way of preventing and detecting oil spills. This is closely related to the legislation and physical planning of oil exploration areas. The area needs both improvement of monitoring tools for detection of spills and monitoring of the recover of remediated or unremediated sites. The literature study indicates that the Russian oil industry and Russian authorities could benefit by the prevention and control plans that have been set up in other oil exploration areas (mainly Alaska).

The weakness of the currently used monitoring and risk assessment system can be summarized in:

- limited resources for surveillance of the number and spatial distribution of oil spills
- inefficient monitoring system controlling polluted and recultivated areas;
- present remediation techniques and criteria is not in conformity with good environmental practise
- absence of recultivation techniques applicable for oil-contaminated marshes and adopted to local conditions;
- absence of differentiated guideline values for oil pollution in peat and related ecological risks assessment;
- absence of objective criteria for inspection of recultivated areas, ranked according to ecological risks
- lack of knowledge regarding plant species optimal for bioremediation of oil contaminated peat and harmonized with native flora
- weak description of oil spill impact in a river basin perspective
- weak description of oil spill impact in a long term perspective
- weak understanding of the full impact of high salinity water (formation water) discharged from oil drilling activities

Next step in the project is to suggest the way forward to reach the needed improvements mentioned above. It will be done by information exchange between partners and stakeholders of the possibility to develop and adjust other remediation technologies as well as adaptation of risk assessment methods used in other countries. The discussions will also result in prioritization of future research projects regarding oil contamination in the region.

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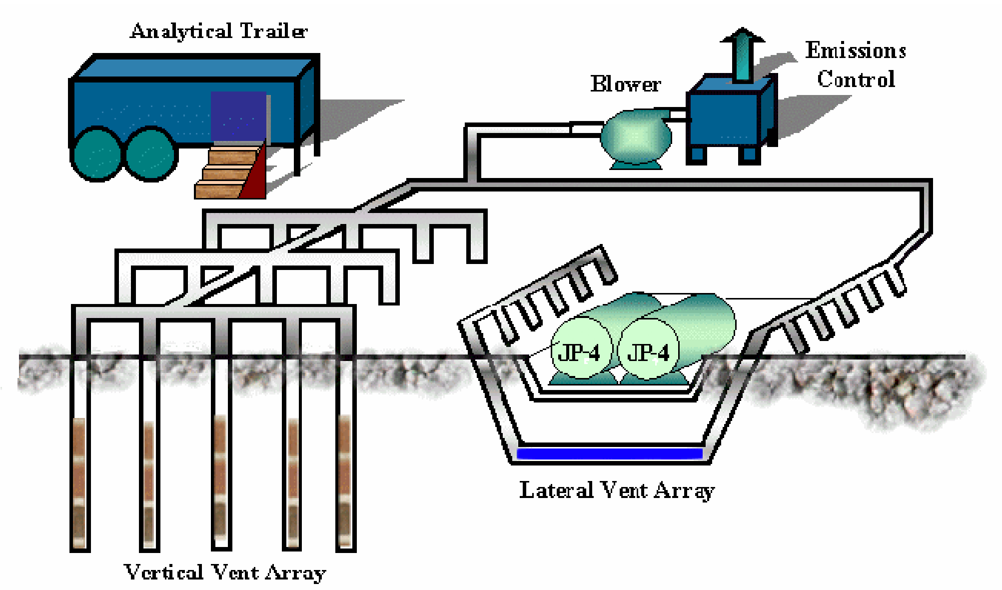
8 Appendix 1a IN-SITU

8.1 Bioventing

Oxygen is delivered to contaminated unsaturated soils by forced air movement (either extraction or injection of air) to increase oxygen concentrations and stimulate biodegradation.

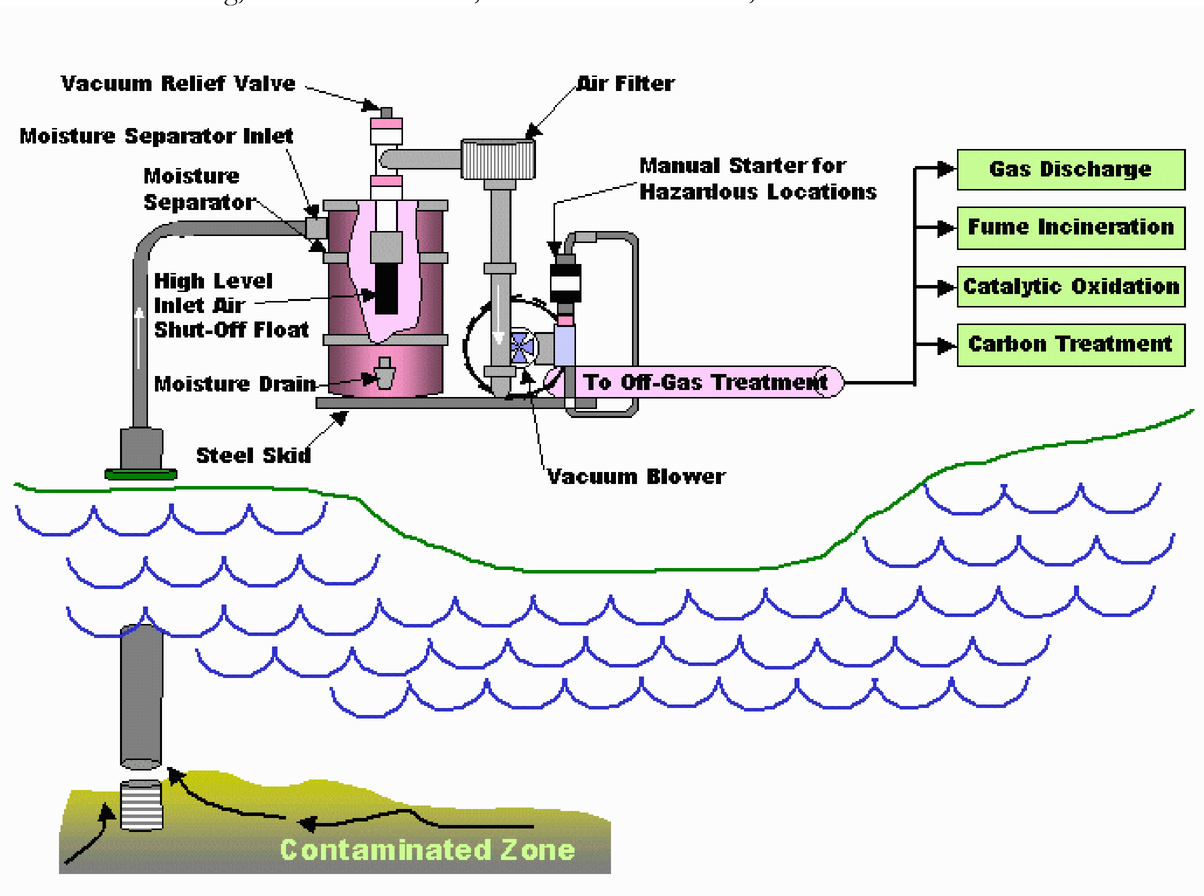


Applicability:
Bioventing techniques have been successfully used to remediate soils contaminated by petroleum hydrocarbons, nonchlorinated solvents, some pesticides, wood preservatives, and other organic chemicals.
While bioremediation cannot degrade inorganic contaminants, bioremediation can be used to change the valence state of inorganics and cause adsorption, uptake, accumulation, and concentration of inorganics in micro or macroorganisms. These techniques, while still largely experimental, show considerable promise of stabilizing or removing inorganics from soil.
Limitations:

- The water table within several feet of the surface, saturated soil lenses, or low permeability soils reduce bioventing performance.
- Vapors can build up in basements within the radius of influence of air injection wells. This problem can be alleviated by extracting air near the structure of concern.
- Extremely low soil moisture content may limit biodegradation and the effectiveness of bioventing.
- Monitoring of off-gases at the soil surface may be required.
- Aerobic biodegradation of many chlorinated compounds may not be effective unless there is a co-metabolite present, or an anaerobic cycle.
- Low temperatures may slow remediation, although successful remediation has been demonstrated in extremely cold weather climates.

8.2 Soil Vapor Extraction

Vacuum is applied through extraction wells to create a pressure/concentration gradient that induces gas-phase volatiles to be removed from soil through extraction wells. This technology also is known as in situ soil venting, in situ volatilization, enhanced volatilization, or soil vacuum extraction.



Applicability

The target contaminant groups for in situ SVE are VOCs and some fuels. The technology is typically applicable only to volatile compounds with a Henry's law constant greater than 0.01 or a vapor pressure greater than 0.5 mm Hg (0.02 inches Hg). Other factors, such as the moisture content, organic content, and air permeability of the soil, will also affect in situ SVE's effectiveness. In situ SVE will not remove heavy oils, metals, PCBs, or dioxins. Because the process involves the continuous flow of air through the soil, however, it often promotes the in situ biodegradation of low-volatility organic compounds that may be present.

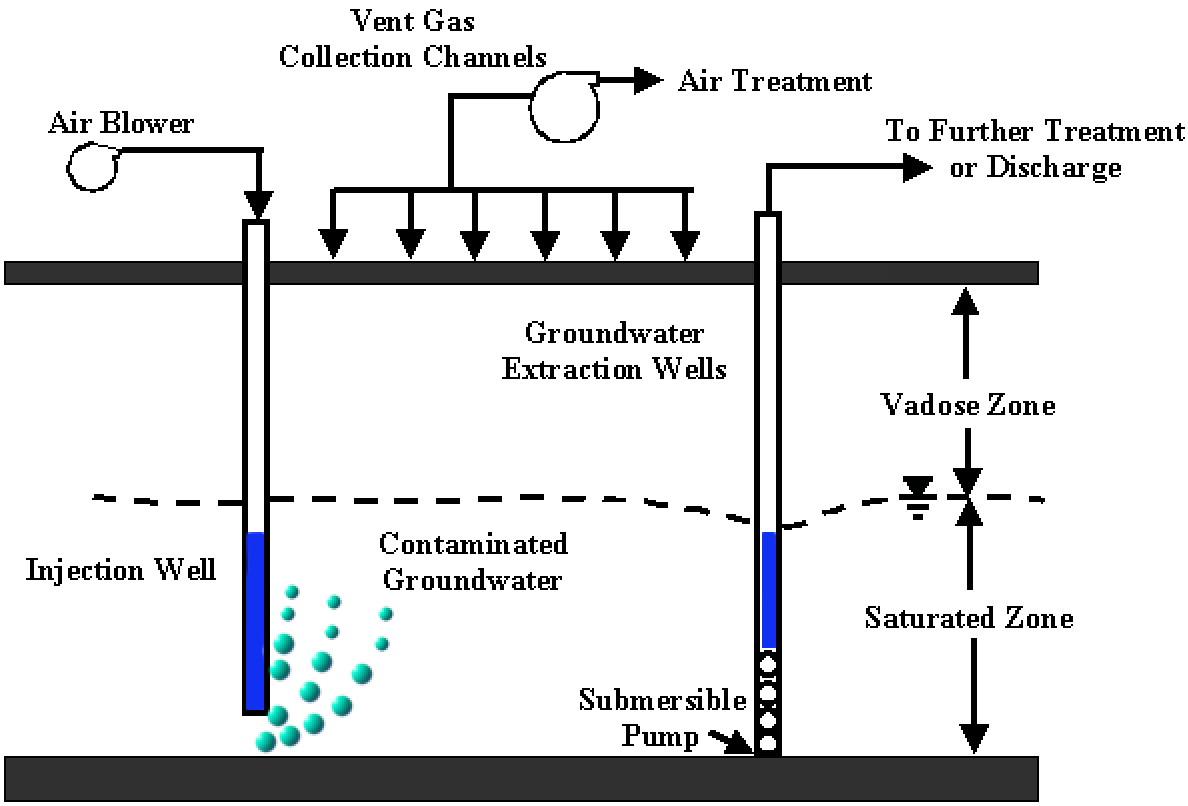
Limitations

- Soil that has a high percentage of fines and a high degree of saturation will require higher vacuums (increasing costs) and/or hindering the operation of the in situ SVE system.
- Large screened intervals are required in extraction wells for soil with highly variable permeabilities or stratification, which otherwise may result in uneven delivery of gas flow from the contaminated regions.
- Soil that has high organic content or is extremely dry has a high sorption capacity of VOCs, which results in reduced removal rates.

- Exhaust air from in situ SVE system may require treatment to eliminate possible harm to the public and the environment.
- As a result of off-gas treatment, residual liquids may require treatment/disposal. Spent activated carbon will definitely require regeneration or disposal.
- SVE is not effective in the saturated zone; however, lowering the water table can expose more media to SVE (this may address concerns regarding LNAPLs).

8.3 Air Sparging

Air sparging is an in situ technology in which air is injected through a contaminated aquifer. Injected air traverses horizontally and vertically in channels through the soil column, creating an underground stripper that removes contaminants by volatilization. This injected air helps to flush (bubble) the contaminants up into the unsaturated zone where a vapor extraction system is usually implemented in conjunction with air sparging to remove the generated vapor phase contamination. This technology is designed to operate at high flow rates to maintain increased contact between ground water and soil and strip more ground water by sparging.
Oxygen added to contaminated ground water and vadose zone soils can also enhance biodegradation of contaminants below and above the water table.
Air sparging has a medium to long duration which may last, generally, up to a few years.



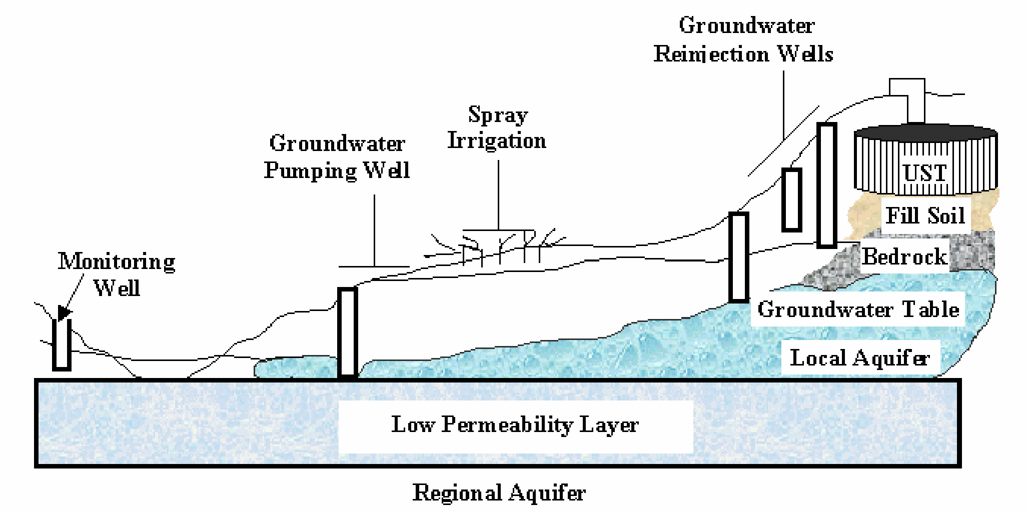
Applicability:
The target contaminant groups for air sparging are VOCs and fuels. Only limited information is available on the process. Methane can be used as an amendment to the sparged air to enhance cometabolism of chlorinated organics.

Limitations:
Factors that may limit the applicability and effectiveness of the process include:

- Air flow through the saturated zone may not be uniform, which implies that there can be uncontrolled movement of potentially dangerous vapors.
- Depth of contaminants and specific site geology must be considered.
- Air injection wells must be designed for site-specific conditions.
- Soil heterogeneity may cause some zones to be relatively unaffected.

8.4 Enhanced Bioremediation

The activity of naturally occurring microbes is stimulated by circulating water-based solutions through contaminated soils to enhance in situ biological degradation of organic contaminants or immobilization of inorganic contaminants. Nutrients, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials.



Applicability:
Bioremediation techniques have been successfully used to remediate soils, sludges, and ground water contaminated with petroleum hydrocarbons, solvents, pesticides, wood preservatives, and other organic chemicals.

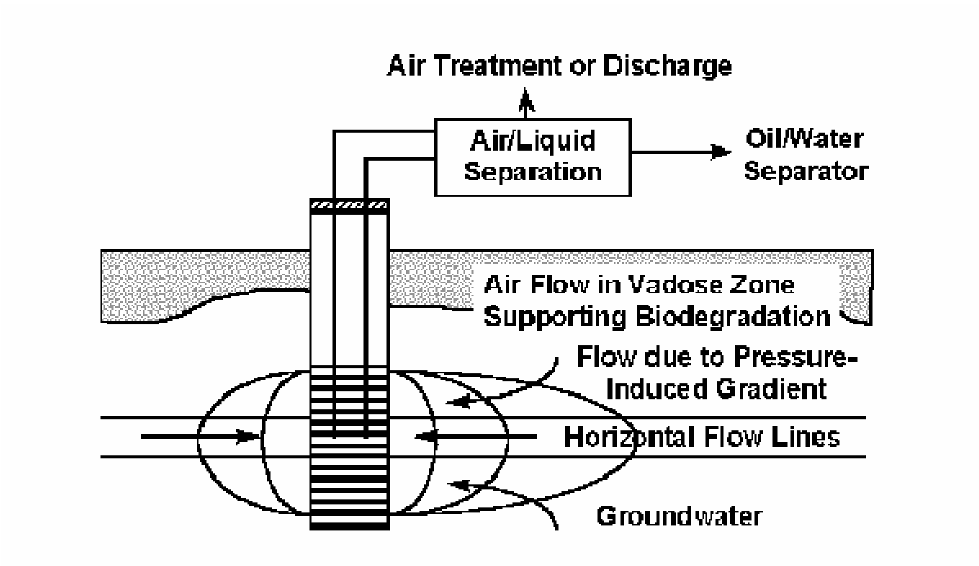
Limitations:

- The circulation of water-based solutions through the soil may increase contaminant mobility and necessitate treatment of underlying ground water.
- Preferential colonization by microbes may occur causing clogging of nutrient and water injection wells.

- Preferential flow paths may severely decrease contact between injected fluids and contaminants throughout the contaminated zones. The system should not be used for clay, highly layered, or heterogeneous subsurface environments because of oxygen (or other electron acceptor) transfer limitations.
- High concentrations of heavy metals, highly chlorinated organics, long chain hydrocarbons, or inorganic salts are likely to be toxic to microorganisms.
- Bioremediation slows at low temperatures.
- Concentrations of hydrogen peroxide greater than 100 to 200 ppm in groundwater inhibit the activity of microorganisms.
- A surface treatment system, such as air stripping or carbon adsorption, may be required to treat extracted groundwater prior to re-injection or disposal.

8.5 Bioslurping

Bioslurping combines the two remedial approaches of bioventing and vacuum-enhanced free-product recovery. Bioventing stimulates the aerobic bioremediation of hydrocarbon-contaminated soils. Vacuum-enhanced free-product recovery extracts LNAPLs from the capillary fringe and the water table.



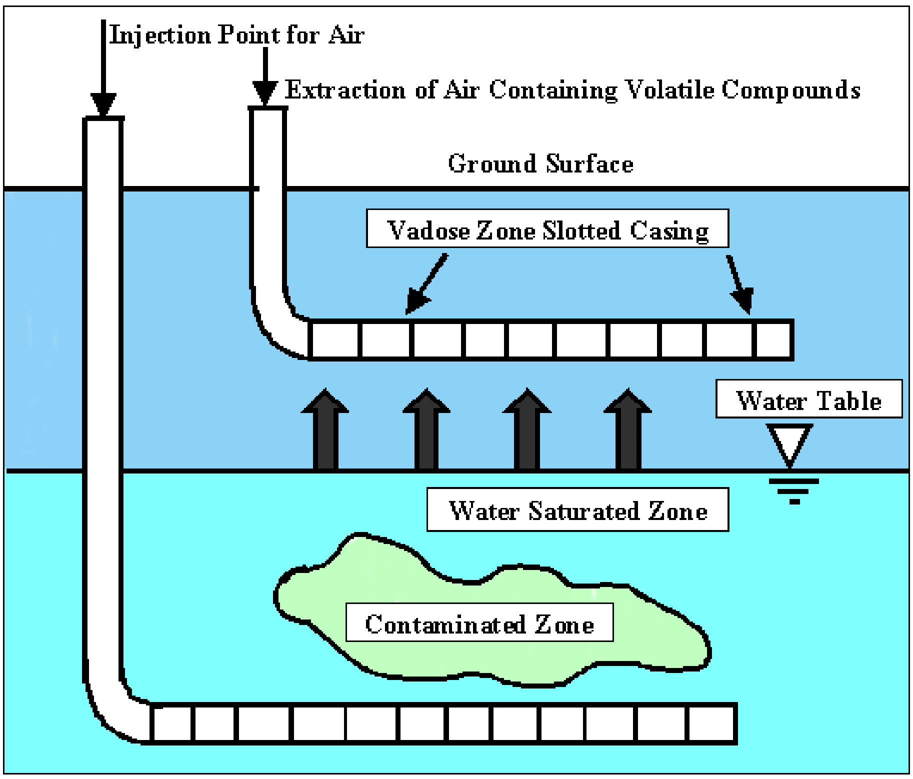
Applicability:
Bioslurping can be successfully used to remediate soils contaminated by petroleum hydrocarbons. It is a cost-effective in situ remedial technology that simultaneously accomplishes LNAPL removal and soil remediation in the vadose zone. Bioslurping is also applicable at sites with a deep ground water table (>30ft.).

Limitations:
- Low soil moisture content may limit biodegradation and the effectiveness of bioventing, which tends to dry out the soils.
- Aerobic biodegradation of many chlorinated compounds may not be effective unless there is a co-metabolite present.
- Low temperatures slow remediation.

- Frequently, the off-gas from the bioslurper system requires treatment before discharge. However, treatment of the off-gas may only be required shortly after the startup of the system as fuel rates decrease.
- At some sites, bioslurper systems can extract large volumes of water that may need to be treated prior to discharge depending on the concentration of contaminants in the process water.
- Since the fuel, water and air are removed from the subsurface in one stream, mixing of the phases occurs. These mixtures may require special oil/water separators or treatment before the process water can be discharged.

8.6 Directional wells

Drilling techniques are used to position wells horizontally, or at an angle, to reach contaminants not accessible by direct vertical drilling. Directional drilling may be used to enhance other in-situ or in-well technologies such as ground water pumping, bioventing, SVE, soil flushing, and in-well air stripping.
Hardware used for directional boring includes wireline coring rigs, hydraulic thrust systems, electric cone penetrometers, steering tracking hardware, sonic drilling, and push coring systems. Hydraulically activated thrust equipment capable of exerting more than 40 tons of thrust is used to push the directional boring heads into the earth. Directional control is obtained by proper positioning of the face of the nonsymmetric boring head. Slow rotation of the boring head will cut and compact the geologic material into the borehole wall. Thrusting a boring head that is not rotating will cause a directional change. The machinery is capable of initiating a borehole, steering down to a desired horizontal depth, continuing at that depth, and then steering back to the surface at a downrange location.



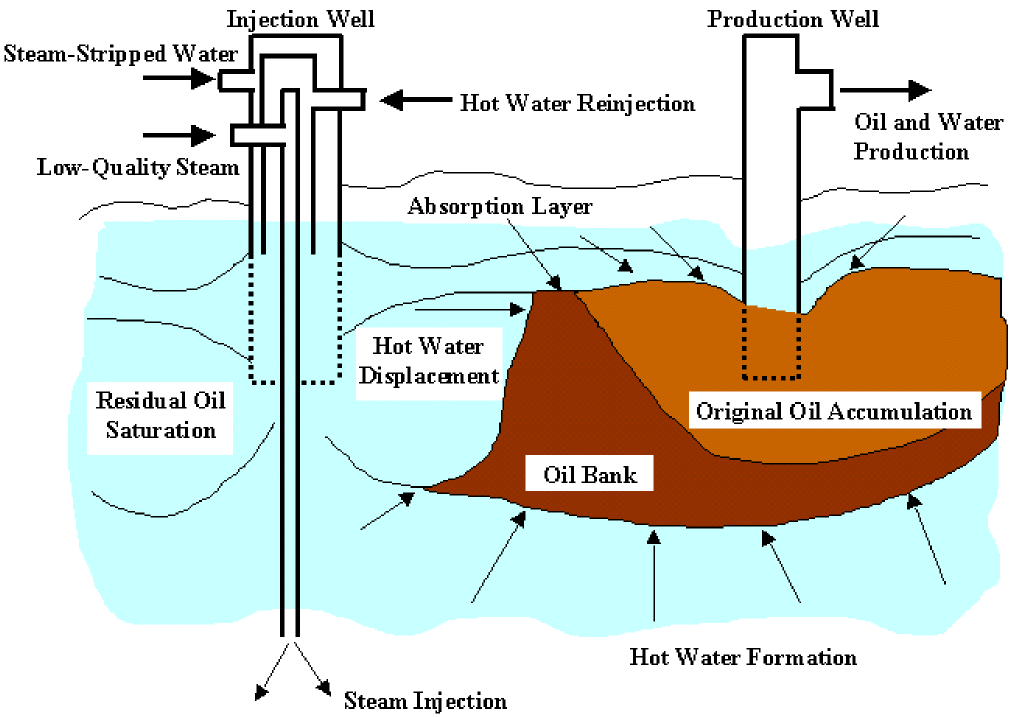
Applicability:
Directional well technology is applicable to the complete range of contaminant groups with no particular target group. It is particularly useful when existing structures interfere with placement of vertical wells.

Limitations:
Factors that may limit the applicability and effectiveness of the process include:

- The potential exists for the wells to collapse.
- Specialized equipment is required.
- Wells are difficult to position precisely.
- Installation of horizontal wells is typically costly.
- Currently, the technology is limited to depths of less than 50 feet.

8.7 Thermal treatment

Steam is forced into an aquifer through injection wells to vaporize volatile and semivolatile contaminants. Vaporized components rise to the unsaturated (vadose) zone where they are removed by vacuum extraction and then treated. Hot water or steam-based techniques include Contained Recovery of Oily Waste (CROW), Steam Injection and Vacuum Extraction (SIVE), In Situ Steam-Enhanced Extraction (ISEE), and Steam-Enhanced Recovery Process (SERP). Hot water or steam flushing/stripping is a pilot-scale technology. In situ biological treatment may follow the displacement and is continued until ground water contaminants concentrations satisfy statutory requirements.
The process can be used to remove large portions of oily waste accumulations and to retard downward and lateral migration of organic contaminants. The process is applicable to shallow and deep contaminated areas, and readily available mobile equipment can be used.
Hot water/steam injection is typically short to medium duration, lasting a few weeks to several months



Applicability:
The target contaminant groups for hot water or steam flushing/stripping are SVOCs and fuels. VOCs also can be treated by this technology, but there are more cost-effective processes for sites contaminated with VOCs.
This technology can be applied at manufactured gas plants, wood-treating sites, petroleum-refining facilities, and other sites with soils containing light to dense organic liquids, such as coal tars, pentachlorophenol solutions, creosote, and petroleum by-products.

Limitations:
Factors that may limit the applicability and effectiveness of the process include:

- Soil type, contaminant characteristics and concentrations, geology, and hydrogeology which will significantly impact process effectiveness.

Thermally enhanced SVE is a full-scale technology that uses electrical resistance/electromagnetic/fiber optic/radio frequency heating or hot-air/steam injection to increase the volatilization rate of semi-volatiles and facilitate extraction. The process is otherwise similar to standard SVE (Treatment Technology Profile 4.7), but requires heat resistant extraction wells. Thermally enhanced SVE is normally a short- to medium-term technology.

Electrical Resistance Heating
Electrical resistance heating uses an electrical current to heat less permeable soils such as clays and fine-grained sediments so that water and contaminants trapped in these relatively conductive regions are vaporized and ready for vacuum extraction. Electrodes are placed directly into the less permeable soil matrix and activated so that electrical current passes through the soil, creating a resistance which then heats the soil. The heat dries out the soil causing it to fracture. These fractures make the soil more permeable allowing the use of SVE to remove the contaminants. The heat created by electrical resistance heating also forces trapped liquids to vaporize and move to the steam zone for removal by SVE. Six-phase soil heating (SPSH) is a typical electrical resistance

heating which uses low-frequency electricity delivered to six electrodes in a circular array to heat soils. With SPSH, the temperature of the soil and contaminant is increased, thereby increasing the contaminant's vapor pressure and its removal rate. SPSH also creates an in situ source of steam to strip contaminants from soil. At this time SPSH is in the demonstration phase, and all large scale in situ projects utilize three-phase soil heating.

➤*Radio Frequency/Electromagnetic Heating*
Radio frequency heating (RFH) is an in situ process that uses electromagnetic energy to heat soil and enhance soil vapor extraction (SVE). RFH technique heats a discrete volume of soil using rows of vertical electrodes embedded in soil (or other media). Heated soil volumes are bounded by two rows of ground electrodes with energy applied to a third row midway between the ground rows. The three rows act as a buried triplate capacitor. When energy is applied to the electrode array, heating begins at the top center and proceeds vertically downward and laterally outward through the soil volume. The technique can heat soils to over 300 °C.
RFH enhances SVE in four ways: (1) contaminant vapor pressure and diffusivity are increased by heating, (2) the soil permeability is increased by drying, (3) an increase in the volatility of the contaminant from in situ steam stripping by the water vapor; and, (4) a decrease in the viscosity which improves mobility. The technology is self limiting; as the soil heats and dries, current will stop flowing. Extracted vapor can then be treated by a variety of existing technologies, such as granular activated carbon or incineration.

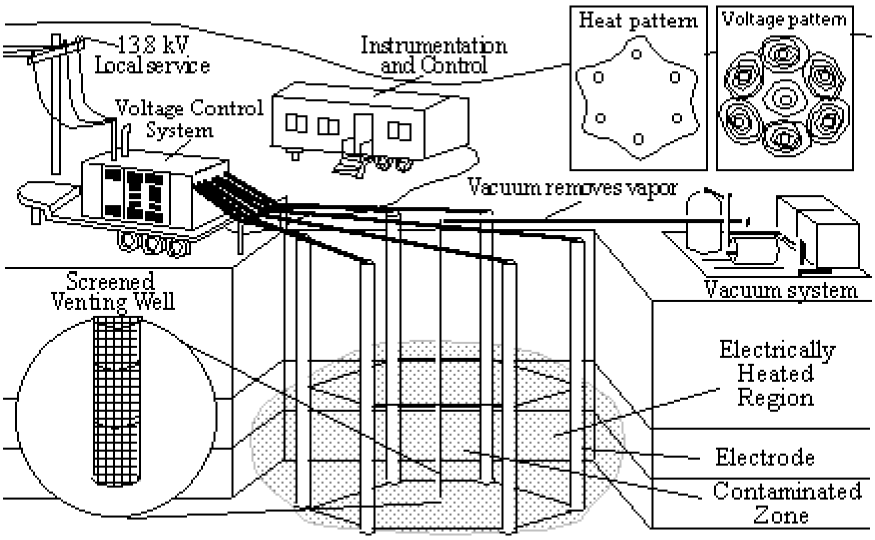
➤*Hot Air/Steam Injection*
Hot air or steam is injected below the contaminated zone to heat up contaminated soil. The heating enhances the release of contaminants form soil matrix. Some VOCs and SVOCs are stripped from contaminated zone and brought to the surface through soil vapor extraction.
Applicability:

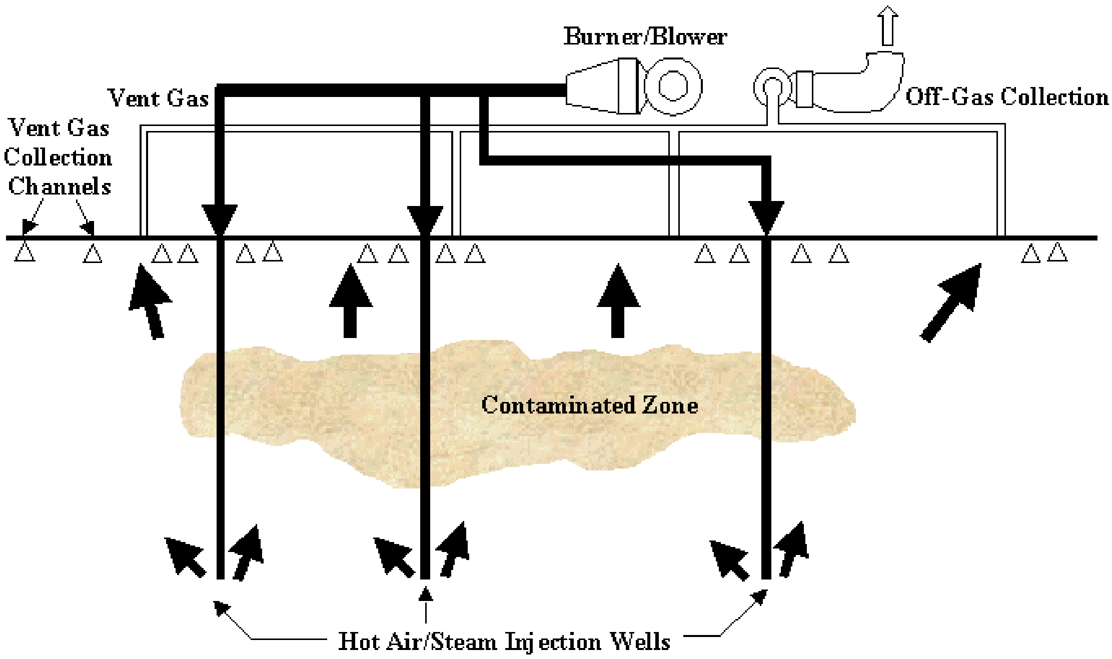
High moisture content is a limitation of standard SVE that thermally enhancement may help overcome. Heating, especially radio frequency heating and electrical resistance heating can improve air flow in high moisture soils by evaporating water. The system is designed to treat SVOCs but will consequently treat VOCs. Thermally enhanced SVE technologies also are effective in treating some pesticides and fuels, depending on the temperatures achieved by the system. After application of this process, subsurface conditions are excellent for biodegradation of residual contaminants.

Limitations:
The following factors may limit the applicability and effectiveness of the process:

- Debris or other large objects buried in the media can cause operating difficulties.
- Performance in extracting certain contaminants varies depending upon the maximum temperature achieved in the process selected.
- Soil that is tight or has high moisture content has a reduced permeability to air, hindering the operation of thermally enhanced SVE and requiring more energy input to increase vacuum and temperature.
- Soil with highly variable permeabilities may result in uneven delivery of gas flow to the contaminated regions.
- Soil that has a high organic content has a high sorption capacity of VOCs, which results in reduced removal rates.

- Air emissions may need to be regulated to eliminate possible harm to the public and the environment. Air treatment and permitting will increase project costs.
- Residual liquids and spent activated carbon may require further treatment.
- Thermally enhanced SVE is not effective in the saturated zone; however, lowering the aquifer can expose more media to SVE (this may address concerns regarding LNAPLs).
- Hot air injection has limitations due to low heat capacity of air.





8.8 Ground water pumping

Possible objectives of ground water pumping include removal of dissolved contaminants from the subsurface, and containment of contaminated ground water to prevent migration.
The first step of any remediation project consists of defining the remedial action objectives to be accomplished at the site. This involves gathering enough background site information and field data to make assessments of remedial requirements and possible cleanup levels. The first determination is whether cleanup or containment will be the most appropriate remedial action. If cleanup is chosen, the level of cleanup must be determined. If containment is chosen, ground water pumping is used as a hydraulic barrier to prevent off-site migration of contaminant plumes.
The next component consists of the design and implementation of the ground water pumping system based on data evaluated in setting the goals and objectives. The criteria for well design, pumping system, and treatment are dependent on the physical site characteristics and contaminant type. Actual treatment may include the design of a train of processes such as gravity segregation, air strippers, carbon systems tailored to remove specific contaminants.
Another component of any ground water extraction system is a ground water monitoring program to verify its effectiveness. Monitoring the remedial with wells and piezometers allows the operator to make iterative adjustments to the system in response to changes in subsurface conditions caused by the remediation.

The final component is determining the termination requirements. Termination requirements are based on the cleanup objectives defined in the initial stage of the remedial process. The termination criteria are also dependent on the specific site aspects revealed during remedial operations.
Although pumping for containment implies no treatment the following treatments usually follow pumping in pump and treat systems. These are briefly described below and in detail in technology profiles 4.41 through 4.51:

4.41 Bioreators:
Contaminants in extracted ground water are put into contact with microorganisms in attached or suspended growth biological reactors. In suspended systems, such as activated sludge, contaminated ground water is circulated in an aeration basin. In attached systems, such as rotating biological contractors and trickling filters, microorganisms are established on an inert support matrix.

4.42 Constructed wetlands:
The constructed wetlands-based treatment technology uses natural geochemical and biological processes inherent in an artificial wetland ecosystem to accumulate and remove metals and other contaminants from influent waters.

4.43 Adsorption/Absorption:
In liquid adsorption, solutes concentrate at the surface of a sorbent, thereby reducing their concentration in the bulk liquid phase. The most common adsorbent is granulated activated carbon (GAC) (see Technology Profile No. 4.51). Other natural and synthetic adsorbents include: forage sponge, lignin adsorption, sorption clays, and synthetic resins.

4.45 Air Stripping:
Volatile organics are partitioned from ground water by increasing the surface area of the contaminated water exposed to air. Aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.
4.46 Granulated Activated Carbon (GAC)/Liquid Phase Carbon Adsorption:
Ground water is pumped through a series of canisters or columns containing activated carbon to

which dissolved organic contaminants adsorb. Periodic replacement or regeneration of saturated carbon is required.

4.48 Ion Exchange:
Ion exchange removes ions from the aqueous phase by the exchange of cations or anions between the contaminants and the exchange medium. Ion exchange materials may consist of resins made from synthetic organic materials that contain ionic functional groups to which exchangeable ions are attached. They also may be inorganic and natural polymeric materials. After the resin capacity has been exhausted, resins can be regenerated for re-use.

4.49 Precipitation/Coagulation/ Flocculation:
This process transforms dissolved contaminants into an insoluble solid, facilitating the contaminant's subsequent removal from the liquid phase by sedimentation or filtration. The process usually uses pH adjustment, addition of a chemical precipitant, and flocculation.

4.50 Separation:
Separation processes seek to detach contaminants from their medium (i.e., ground water and/or binding material that contain them). Ex situ separation of waste stream can be performed by many processes: (1) distillation, (2) filtration/ultrafiltration/microfiltration, (3) freeze crystallization, (4) membrane pervaporation and (5) reverse osmosis.

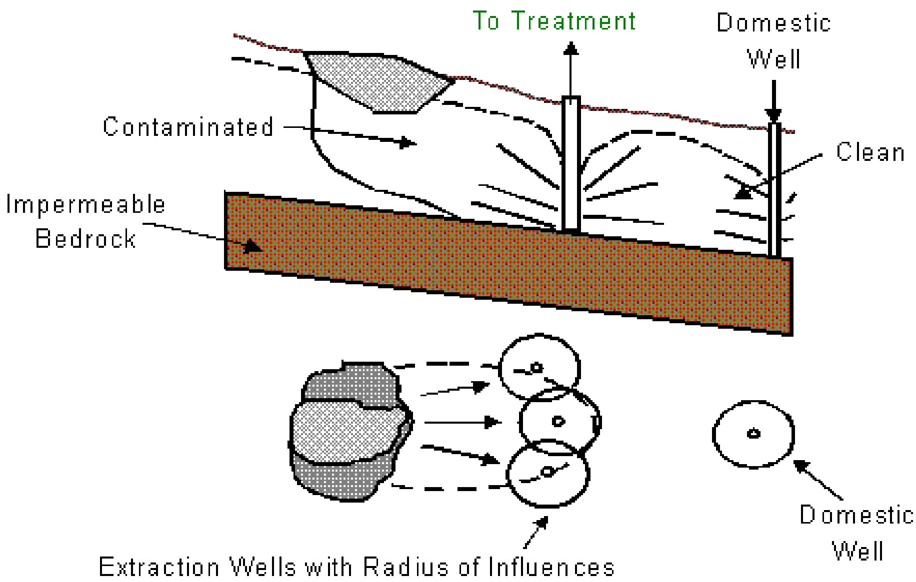
4.51 Sprinkler Irrigation:
Wastewater is distributed over the top of the filter bed through which wastewater is trickled. The organic contaminants in wastewater are degraded by the microorganisms attached to the filter medium.

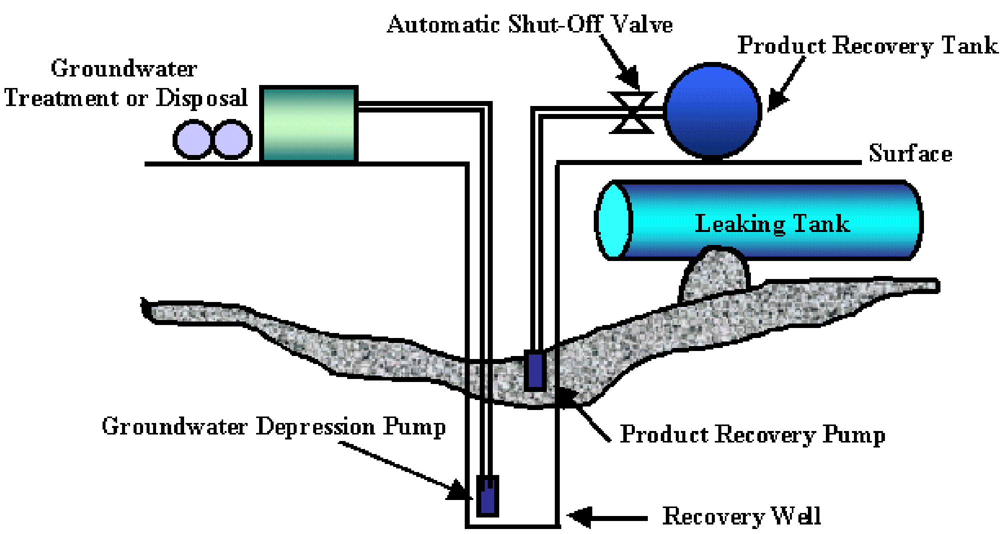
➤*Surfactant Enhanced Recovery*
The application of surfactants micelles or steam to the ground water can facilitate the ground water pumping process by increasing the mobility and solubility of the contaminants sorbed to the soil matrix. This material can also facilitate the entrainment of hydrophobic contaminants to allow removal and assures that multi-phase contaminants can be effectively removed. Thus it can increase the contaminant mass removal per pore volume of ground water flushing through the contaminated zone.
The implementation of surfactant-enhanced recovery requires the injection of surfactants into a contaminated aquifer. Typical systems utilize a pump to extract ground water at some distance away from the injection point. The extracted ground water is treated ex situ to separate the injected surfactants from the contaminants and ground water. In order to be cost-effective, the design of the surfactant-enhanced recovery system is critical. Once the surfactants have separated from the ground water they can be re-injected into the subsurface. Contaminants must be separated from the ground water and treated prior to discharge of the extracted ground water.

➤*Drawdown Pumping*
Pump drawdown nonaqueous-phase liquid (NAPL) recovery systems are designed to pump NAPL and ground water from recovery wells or trenches. Pumping removes water and lowers the water table near the extraction area to create a cone of depression. The cone of depression in the vicinity of the extraction well produces a gravity head that pushes flow of NAPL toward the well and increases the thickness of the NAPL layer in the well. Each foot of ground water depression provides a driving head equivalent to a pressure difference of 0.45 psi. In most cases, the production of a cone of depression will increase NAPL recovery rates.

Pumping may be accomplished with one or two pumps. In the single-pump configuration, one pump withdraws both water and NAPL. The dual-pump configuration uses one pump located below the water table to remove water and a second located in the NAPL layer to recover NAPL. A single-pump system reduces capital and operating costs and allows simpler control systems and operation, but produces a stream of mixed water and NAPL that must then be separated.

The Dual Phase Extraction (DPE) process for undissolved liquid-phase organics, also known as free product recovery, is used primarily in cases where a fuel hydrocarbon lens more than 20 centimeters (8 inches) thick is floating on the water table. The free product is generally drawn up to the surface by a pumping system. Following recovery, it can be disposed of, re-used directly in an operation not requiring high-purity materials, or purified prior to re-use. Systems may be designed to recover only product, mixed product and water, or separate streams of product and water. Dual phase extraction is a full-scale technology.





Applicability:
The first step in determining whether ground water pumping is an appropriate remedial technology is to conduct a site characterization investigation. Site characteristics, such as hydraulic conductivity, will determine the range of remedial options possible. Chemical properties of the site and plume need to be determined to characterize transport of the contaminant and evaluate the feasibility of ground water pumping. To determine if ground water pumping is appropriate for a site, one needs to know the history of the contamination event, the properties of the subsurface, and the biological and chemical contaminant characteristics. Identifying the chemical and physical site characteristics, locating the ground water contaminant plume in three dimensions, and determining aquifer and soil properties are necessary in designing an effective ground water pumping strategy.
Surfactant-enhanced recovery are most applicable for contaminated sites with enhanced dense, nonaqueous-phase liquids (DNAPLs).

Drawdown pumping is effective for NAPL recovery when the aquifer has moderate to high hydraulic conductivity and a thick layer of low-viscosity NAPL. An aquifer with high hydraulic conductivity gives less flow resistance of NAPL into the well. A thick layer of NAPL allows the pumping system to collect a high proportion of NAPL in relation to the amount of ground water. For best operation, the NAPL thickness should be sufficient to completely cover the pump suction port.

Drawdown pumping is a commercially available technology that can be easily implemented with conventional pumps in wells or trenches. System installation costs are low to moderate, but the cost per amount of NAPL recovered varies greatly.

Limitations:
The following factors may limit the applicability and effectiveness of ground water pumping as part of the remedial process:

- The potentially long time necessary to achieve the remediation goal
- System designs fail to contain the contaminant as predicted, allowing the plume to migrate and failure of the pumping equipment.
- Residual saturation of the contaminant in the soil pores cannot be removed by ground water pumping. Contaminants tend to be sorbed in the soil matrix. Ground water pumping is not applicable to contaminants with high residual saturation, contaminants with high sorption capabilities, and homogeneous aquifers with hydraulic conductivity less than 10^{-5} cm/sec.
- The cost of permitting procuring and operating treatment systems is high. Additional cost may also be attributed to the disposal of spend carbon and other treatment residuals and wastes.
- Biofouling of the extraction wells and associated treatment stream is a common problem which can severely affect system performance. The potential for this problem should be evaluated prior to the installation.

The following factors may limit the applicability and effectiveness of surfactant-enhanced recovery:

- Subsurface heterogeneities, as with most ground water remediation technologies, present challenges to the successful implementation of surfactant-enhanced recovery
- Potential toxic effects of residual surfactants in the subsurface
- Off-site migration of contaminants due to the increase solubility achieved with surfactant injection Obtaining regulatory approval to inject surfactants into an aquifer.

The following factors may limit the applicability and effectiveness of drawdown pumping:

- Drawdown pumping generally produces large volumes of water in the process of recovering the free product.
- The production of a cone depression in the water table can smear the free product or trap the fuel in the saturated zone when the water table returns to its original level.

8.9 Phytoremediation

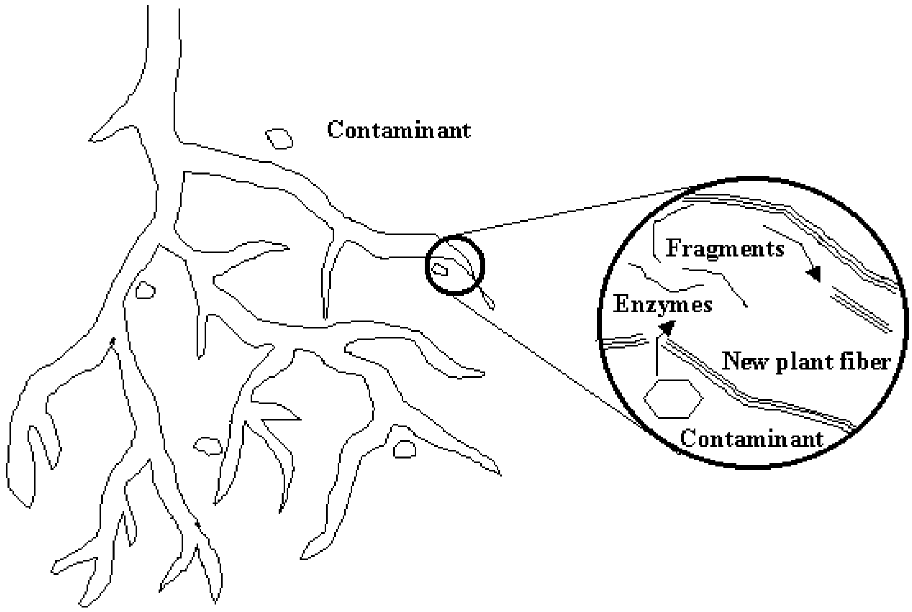
Phytoremediation is a set of processes that uses plants to clean contamination in ground water and surface water. The treatment of metals or other inorganic contamination has been discussed in Section 4.6 (Phytoremediation for Soil). There are several ways plants can be used for the phytoremediation. These mechanisms include enhanced rhizosphere biodegradation, hydraulic control, phyto-degradation and phyto-volatilization.

➤*Enhanced Rhizosphere Biodegradation*
Enhanced rhizosphere biodegradation takes place in the soil surrounding plant roots. Natural substances released by plant roots supply nutrients to microorganisms, which enhances their ability to biodegrade organic contaminants. Plant roots also loosen the soil and then die, leaving paths for transport of water and aeration. This process tends to pull water to the surface zone and dry the lower saturated zones.

➤*Hydraulic Control*
Depending on the type of trees, climate, and season, trees can act as organic pumps when their roots reach down towards the water table and establish a dense root mass that takes up large quantities of water.

➤*Phyto-degradation*
Phyto-degradation is the metabolism of contaminants within plant tissues. Plants produce enzymes, such as dehalogenase and oxygenase, that help catalyze degradation. Investigations are proceeding to determine if both aromatic and chlorinated aliphatic compounds are amenable to phyto-degradation.

➤*Phyto-volatilization*
Phyto-volatilization occurs as plants take up water containing organic contaminants and release the contaminants into the air through their leaves. Plants can also break down organic contaminants and release breakdown products into air through leaves.



Applicability:
Phytoremediation can be used to clean up organic contaminants from surface water, ground water, leachate, and municipal and industrial wastewater.
Plants also produce enzymes, such as dehalogenase and oxygenase, which help catalyze degradation.

Limitations:
There are a number of limitations to phytoremediation

- It is limited to shallow soils, streams, and ground water.
- High concentrations of hazardous materials can be toxic to plants.
- It involves the same mass transfer limitations as other biotreatments.
- Climatic or seasonal conditions may interfere or inhibit plant growth, slow remediation efforts, or increase the length of the treatment period.
- It can transfer contamination across media, e.g., from soil to air.
- It is not effective for strongly sorbed (e.g., PCBs) and weakly sorbed contaminants.
- Phytoremediation will likely require a large surface area of land for remediation.
- The toxicity and bioavailability of biodegradation products is not always known. Products may be mobilized into ground water or bioaccumulated in animals. More research is needed to determine the fate of various compounds in the plant metabolic cycle to ensure that plant droppings and products manufactured by plants do not contribute toxic or harmful chemicals into the food chain or increase risk exposure to the general public.

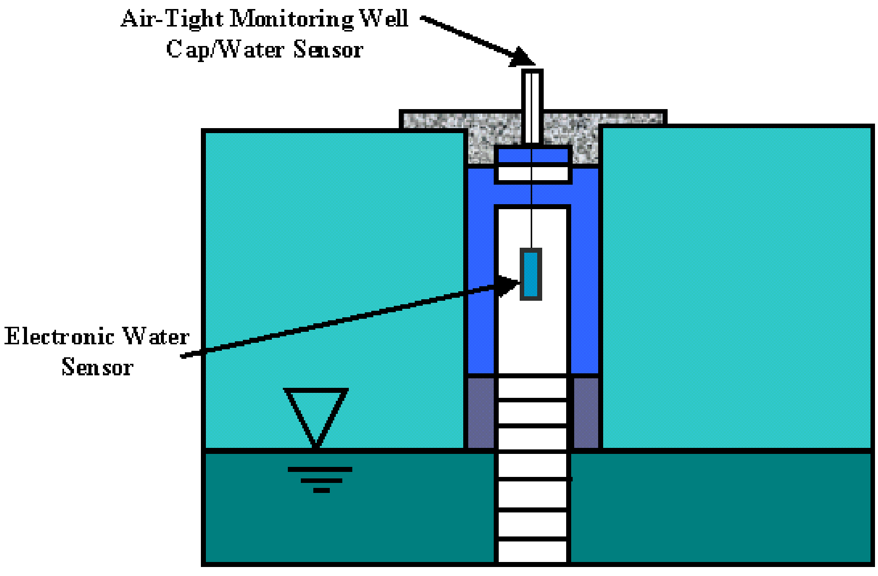
8.10 Monitored Natural Attenuation

Natural subsurface processes such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials are allowed to reduce contaminant concentrations to acceptable levels. Natural attenuation is not a "technology" per se, and there is significant debate among technical experts about its use at hazardous waste sites. Consideration of this option usually requires modeling and evaluation of contaminant degradation rates and pathways and predicting contaminant concentration at down gradient receptor points, especially when plume is still expanding/migrating. The primary objective of site modeling is to demonstrate that natural processes of contaminant degradation will reduce contaminant concentrations below regulatory standards or risk-based levels before potential exposure pathways are completed. In addition, long term monitoring must be conducted throughout the process to confirm that degradation is proceeding at rates consistent with meeting cleanup objectives.

Natural attenuation is not the same as "no action," although it often is perceived as such. CERCLA requires evaluation of a "no action" alternative but does not require evaluation of natural attenuation. Natural attenuation is considered in the Superfund program on a case-by-case basis, and guidance on its use is still evolving.

Compared with other remediation technologies, natural attenuation has the following advantages:

- Less generation or transfer of remediation wastes;
- Less intrusive as few surface structures are required;
- May be applied to all or part of a given site, depending on site conditions and cleanup objectives;
- Natural attenuation may be used in conjunction with, or as a follow-up to, other (active) remedial measures; and
- Overall cost will likely be lower than active remediation.



Applicability:

Target contaminants for natural attenuation are VOCs and SVOCs and fuel hydrocarbons. Fuel and halogenated VOCs are commonly evaluated for natural attenuation. Pesticides also can be allowed to naturally attenuate, but the process may be less effective and may be applicable to only some compounds within the group. Additionally, natural attenuation may be appropriate for some metals when natural attenuation processes result in a change in the valence state of the metal that results in immobilization (e.g., chromium).

Limitations:

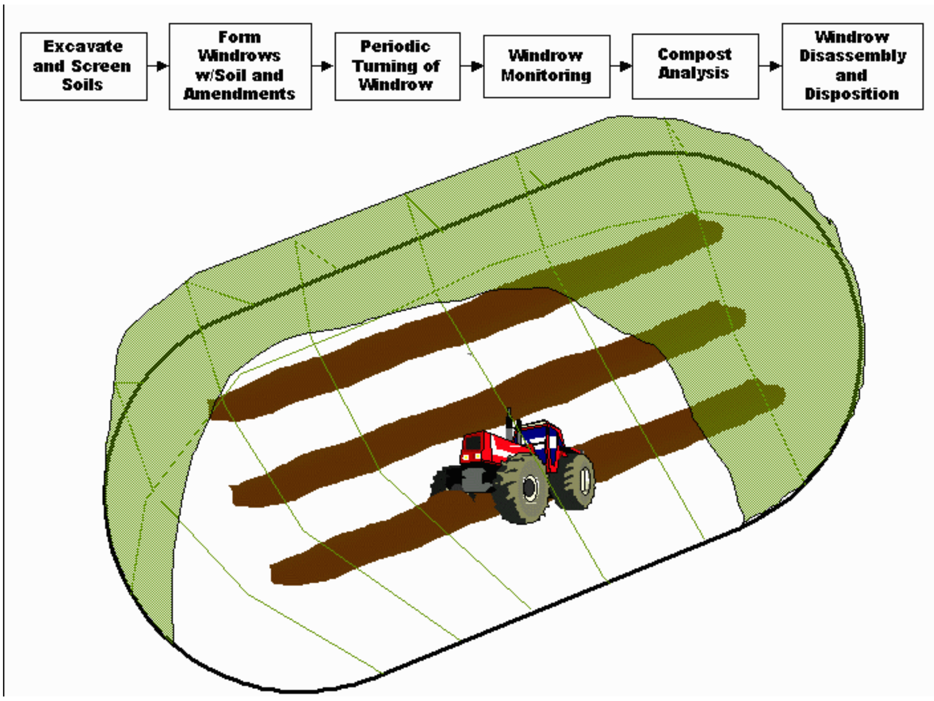
Factors that may limit applicability and effectiveness include:

- Data used as input parameters for modeling need be collected.
- Intermediate degradation products may be more mobile and more toxic than the original contaminant.
- Natural attenuation is not appropriate where imminent site risks are present.
- Contaminants may migrate before they are degraded.
- Institutional controls may be required, and the site may not be available for reuse until contaminant levels are reduced.
- If free product exists, it may have to be removed.
- Some inorganics can be immobilized, such as mercury, but they will not be degraded.
- Long term monitoring and associated costs.
- Longer time frames may be required to achieve remediation objectives, compared to active remediation.
- The hydrologic and geochemical conditions amenable to natural attenuation are likely to change over time and could result in renewed mobility of previously stabilized contaminants and may adversely impact remedial effectiveness; and
- More extensive outreach efforts may be required in order to gain public acceptance of natural attenuation.

9 Appendix 1b EX-SITU

9.1 Composting

Contaminated soil is excavated and mixed with bulking agents and organic amendments such as wood chips, hay, manure, and vegetative (e.g., potato) wastes. Proper amendment selection ensure adequate porosity and provides a balance of carbon and nitrogen to promote thermophilic, microbial activity.



Applicability:
The composting process may be applied to soils and lagoon sediments contaminated with biodegradable organic compounds. Pilot and full-scale projects have demonstrated that aerobic, thermophilic composting is able to reduce the concentration of explosives (TNT, RDX, and HMX), ammonium picrate (or yellow-D), and associated toxicity to acceptable levels. Aerobic, thermophilic composting is also applicable to PAH-contaminated soil. All materials and equipment used for composting are commercially available.

Limitations:

- Substantial space is required for composting.
- Excavation of contaminated soils is required and may cause the uncontrolled release of VOCs.
- Composting results in a volumetric increase in material because of the addition of amendment material.
- Although levels of metals may be reduced via dilution, heavy metals are not treated by this method. Also high levels of heavy metals can be toxic to the microorganisms

9.2 Land Treatment

Contaminated surface soil is treated in place by tilling to achieve aeration, and if necessary, by addition of amendments. Periodically tilling, to aerate the waste, enhances the biological activity.

Applicability:

Soil bioremediation has been proven most successful in treating petroleum hydrocarbons and other less volatile, biodegradable contaminants. Because lighter, more volatile hydrocarbons such as gasoline are treated very successfully by processes that use their volatility [i.e., soil vapor (vacuum) extraction and bioventing], the use of aboveground bioremediation is usually limited to heavier hydrocarbons. As a rule of thumb, the higher the molecular weight (and the more rings with a PAH), the slower the degradation rate. Also, the more chlorinated or nitrated the compound, the more difficult it is to degrade. (Note: Many mixed products and wastes include some volatile components that transfer to the atmosphere before they can be degraded.)

Limitations:

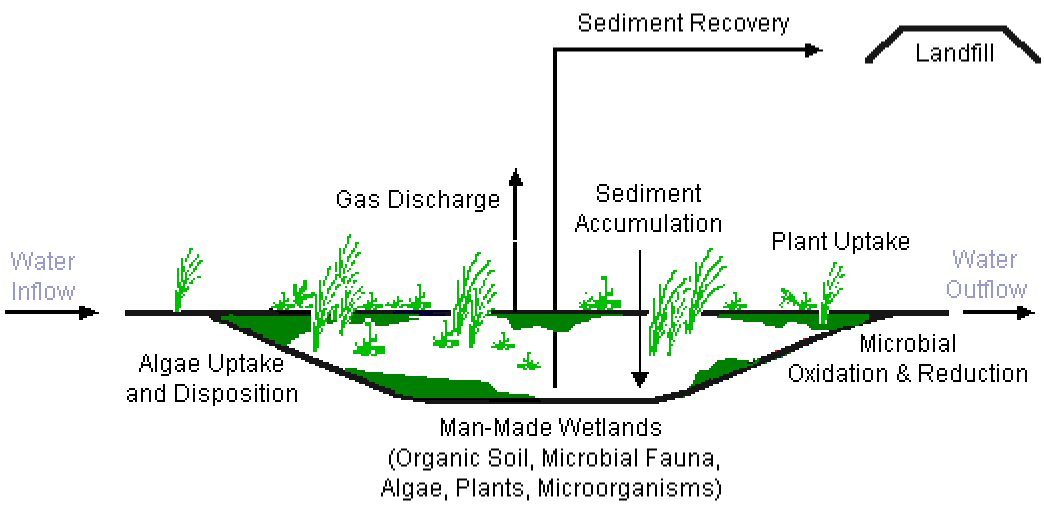
- A large amount of space is required.
- Conditions affecting biological degradation of contaminants (e.g., temperature, rain fall) are largely uncontrolled, which increases the length of time to complete remediation.
- Inorganic contaminants will not be biodegraded.
- Volatile contaminants, such as solvents, must be pretreated because they would evaporate into the atmosphere, causing air pollution.
- Dust control is an important consideration, especially during tilling and other material handling operations.
- Presence of metal ions may be toxic to the microbes and possibly leach from the contaminated soil into the ground.
- Runoff collection facilities must be constructed and monitored.
- Topography, erosion, climate, soil stratigraphy, and permeability of the soil at the site must be evaluated to determine the optimum design of facility.
- Waste constitutes may be subject to "Land-ban" regulation and thus may not be applied to soil for treatment by land treatment (e.g., some petroleum sludges).
- The depth of treatment is limited to the depth of achievable tilling (normally 18 inches).

9.3 Constructed wetlands

Although the technology incorporates principal components of wetland ecosystems; including organic soils, microbial fauna, algae, and vascular plants; microbial activity is responsible for most of the remediation.
Influent waters with high metal concentrations and low pH flow through the aerobic and anaerobic zones of the wetland ecosystem. Metals are removed through ion exchange, adsorption, absorption, and precipitation with geochemical and microbial oxidation and reduction. Ion exchange occurs as metals in the water contact humic or other organic substances in the wetland. Wetlands constructed for this purpose often have little or no soil instead they have straw, manure or compost. Oxidation and reduction reactions catalyzed by bacteria that occur in the aerobic and anaerobic zones, respectively, play a major role in precipitating metals as hydroxides and sulfides. Precipitated and adsorbed metals settle in quiescent ponds or are filtered out as water percolates through the medium or the plants.

Influent water with explosive residues or other contaminants flows through and beneath the gravel surface of a gravel-based wetland. The wetland, using emergent plants, is a coupled anaerobic-aerobic system. The anaerobic cell uses plants in concert with natural microbes to degrade the contaminant. The aerobic, also known as the reciprocating cell, further improves water quality through continued exposure to the plants and the movement of water between cell compartments.

Wetland treatment is a long-term technology intended to operate continously for years.



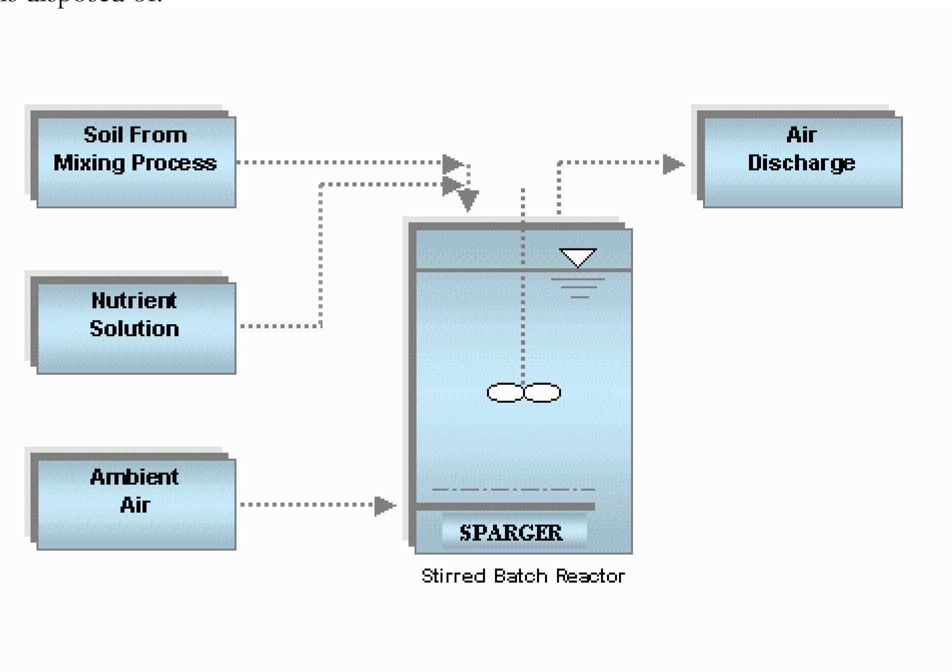
Applicability:
Constructed wetlands have most commonly been used in wastewater treatment for controlling organic matter; nutrients, such as nitrogen and phosphorus; and suspended sediments. The wetlands process is also suitable for controlling trace metals, and other toxic materials. Additionally, the treatment has been used to treat acid mine drainage generated by metal or coal mining activities. These wastes typically contain high metals concentrations and are acidic. The process can be adapted to treat neutral and basic tailings solutions.

Limitations:
The wetlands remediation technology must be adjusted to account for differences in geology, terrain, trace metal composition, and climate in the metal mining regions of the western United States.
The following factors may limit the applicability and effectiveness of the process:

- The long-term effectiveness of constructed wetlands is not well known. Wetland aging may be a problem which may contribute to a decrease in contaminant removal rates over time.
- The cost of building an artificial wetland varies considerably from project and may not be financially viable for many sites.
- Temperature and fluctuations in flow affect wetland function and can cause a wetland to display inconsistent contaminant removal rates.
- Colder conditions slow the rate at which the wetland is able break down contaminants.
- A heavy flow of incoming water can overload the removal mechanisms in a wetland, while a dry spell can damage plants and severely limit wetland function.

9.4 Slurry Phase Biological Treatment

An aqueous slurry is created by combining soil, sediment, or sludge with water and other additives. The slurry is mixed to keep solids suspended and microorganisms in contact with the soil contaminants. Upon completion of the process, the slurry is dewatered and the treated soil is disposed of.



Applicability:
Bioremediation techniques have been successfully used to remediate soils, sludges, and sediments contaminated by explosives, petroleum hydrocarbons, petrochemicals, solvents, pesticides, wood preservatives, and other organic chemicals. Bioreactors are favored over in

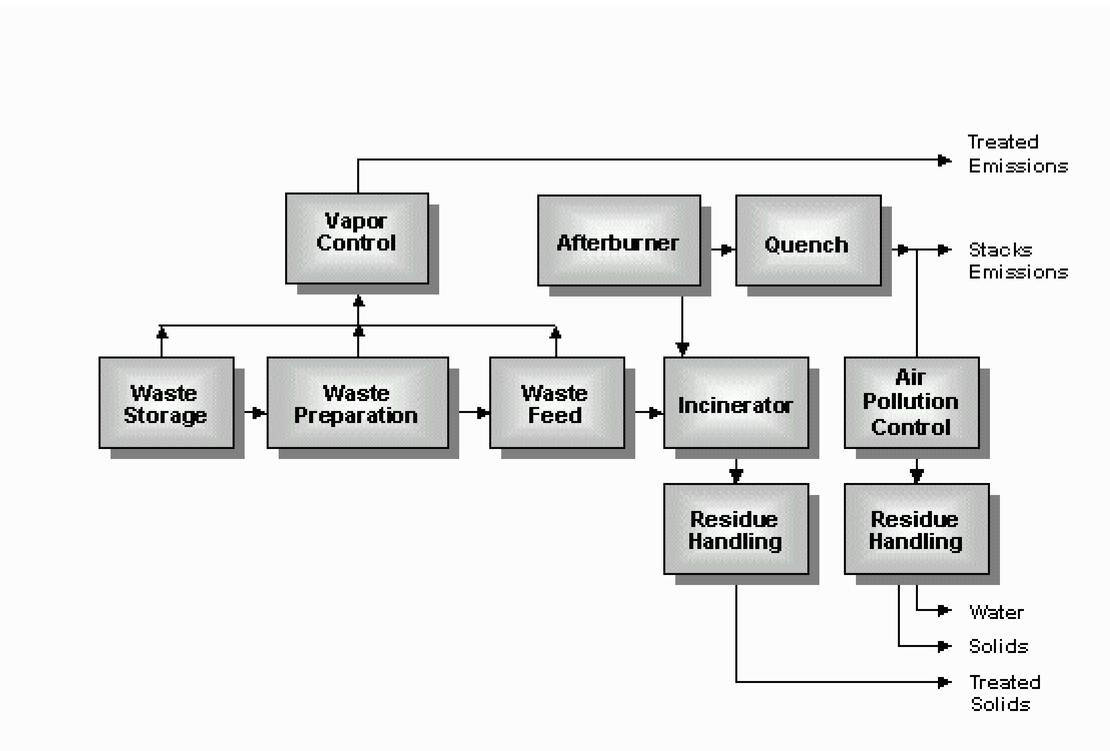
situ biological techniques for heterogenous soils, low permeability soils, areas where underlying ground water would be difficult to capture, or when faster treatment times are required. Slurry-phase bioreactors are used primarily to treat nonhalogenated SVOCs and VOCs in excavated soils or dredged sediments. Ordnance compounds may also be treated. Slurry-phase bioreactors containing cometabolites and specially adapted microorganisms are both used to treat halogenated VOCs and SVOCs, pesticides, and PCBs in excavated soils and dredged sediments.

Limitations:

- Excavation of contaminated media is required, except for lagoon implementation.
- Sizing of materials prior to putting them into the reactor can be difficult and expensive. Nonhomogeneous soils and clayey soils can create serious materials handling problems. In the case of free phase contaminant, precluded removal is mandatory.
- Dewatering soil fines after treatment can be expensive.
- An acceptable method for disposing of nonrecycled wastewaters is required

9.5 Incineration

High temperatures, 870-1,200 °C are used to combust (in the presence of oxygen) organic constituents in hazardous wastes.



Applicability:

Incineration is used to remediate soils contaminated with explosives and hazardous wastes, particularly chlorinated hydrocarbons, PCBs, and dioxins.

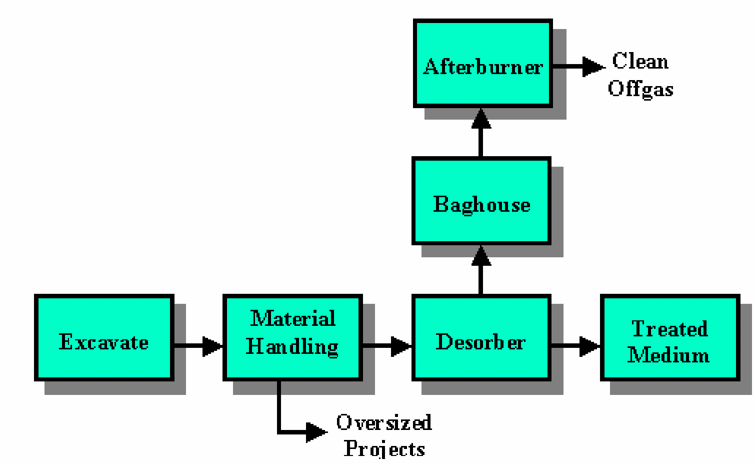
Limitations:

- Only one off-site incinerator is permitted to burn PCBs and dioxins.
- There are specific feed size and materials handling requirements that can impact applicability or cost at specific sites.
- Heavy metals can produce a bottom ash that requires stabilization.
- Volatile heavy metals, including lead, cadmium, mercury, and arsenic, leave the combustion unit with the flue gases and require the installation of gas cleaning systems for removal.
- Metals can react with other elements in the feed stream, such as chlorine or sulfur, forming more volatile and toxic compounds than the original species. Such compounds are likely to be short-lived reaction intermediates that can be destroyed in a caustic quench.
- Sodium and potassium form low melting point ashes that can attack the brick lining and form a sticky particulate that fouls gas ducts.

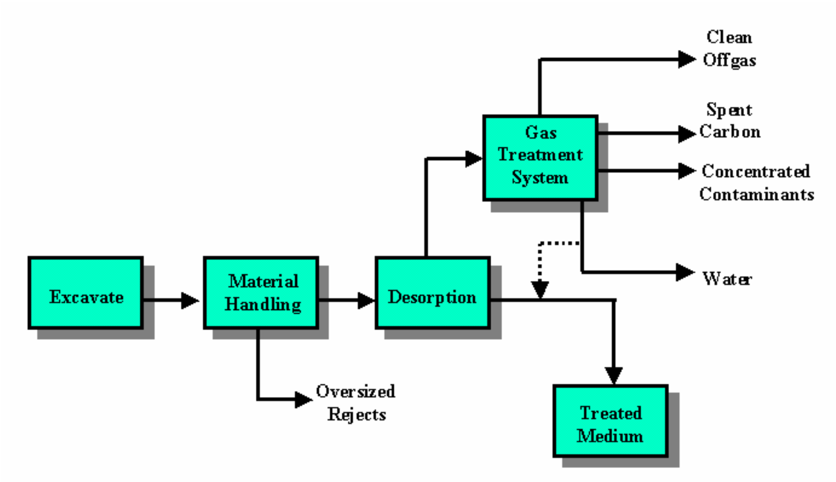
9.6 Thermal Desorption

Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system.

High Temperature Thermal Desorption (HTTD)



Low Temperature Thermal Desorption (LTTD)



Applicability:
Thermal desorption systems have varying degrees of effectiveness against the full spectrum of organic contaminants.
The target contaminant groups for **LTTD** systems are nonhalogenated VOCs and fuels. The technology can be used to treat SVOCs at reduced effectiveness.
The target contaminants for **HTTD** are SVOCs, PAHs, PCBs, and pesticides; however, VOCs and fuels also may be treated, but treatment may be less cost-effective. Volatile metals may be removed by HTTD systems. The presence of chlorine can affect the volatilization of some metals, such as lead. The process is applicable for the separation of organics from refinery wastes, coal tar wastes, wood-treating wastes, creosote-contaminated soils, hydrocarbon-contaminated soils, mixed (radioactive and hazardous) wastes, synthetic rubber processing waste, pesticides and paint wastes.

Limitations:
- There are specific particle size and materials handling requirements that can impact applicability or cost at specific sites.
- Dewatering may be necessary to achieve acceptable soil moisture content levels.
- Highly abrasive feed potentially can damage the processor unit.
- Heavy metals in the feed may produce a treated solid residue that requires stabilization.
- Clay and silty soils and high humic content soils increase reaction time as a result of binding of contaminants.

10 Appendix 2. Litterature survey

SCOPUS
SCOPUS Documents

Nyman, J.A., Klerks, P.L., Bhattacharyya, S.
Effects of chemical additives on hydrocarbon disappearance and biodegradation in freshwater marsh microcosms
(2007) *Environmental Pollution*, 149 (2), pp. 227-238.

Department of Biology, University of Louisiana at Lafayette, P.O. Box 42451, Lafayette, LA 70504-2451, United States

Abstract
We determined how a cleaner and a dispersant affected hydrocarbon biodegradation in wetland soils dominated by the plant Panicum hemitomon, which occurs throughout North and South America. Microcosms received no hydrocarbons, South Louisiana crude, or diesel; and no additive, a dispersant, or a cleaner. We determined the concentration of four total petroleum hydrocarbon (TPH) measures and 43 target hydrocarbons in water and sediment fractions 1, 7, 31, and 186 days later. Disappearance was distinguished from biodegradation via hopane-normalization. After 186 days, TPH disappearance ranged from 24% to 97%. There was poor correlation among the four TPH measures, which indicated that each quantified a different suite of hydrocarbons. Hydrocarbon disappearance and biodegradation were unaltered by these additives under worse-case scenarios. Any use of these additives must generate benefits that outweigh the lack of effect on biodegradation demonstrated in this report, and the increase in toxicity that we reported earlier.

Author Keywords
Bioremediation; Crude oil; Diesel; Remediation; Wetland

Document Type: Article
Source: Scopus

Ji, G.[a b] , Sun, T.[b] , Ni, J.[a]
Impact of heavy oil-polluted soils on reed wetlands
(2007) *Ecological Engineering*, 29 (3), pp. 272-279.

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Abstract
The impacts of heavy oil-contaminated soils on a reed wetland were studied during a 3-year field experiment in China's Liaohe Oilfield. Contaminated soils with a 30% heavy oil concentration were spread in the reed wetland in April of the first 2 years with 0.2, 2, 6, 18, and 0 kg of oil-polluted soil m-2 for 4 reed beds and a control. In the third year no polluted soil was spread in the wetland. Results indicated that removal efficiencies in 0-80 cm soil layers were between 88 and 92% in the first 2 years, and up to 96% in the third year. The soil profile analysis pointed out that in the third harvest season, there was little residual heavy oil in soil layers 60-80 cm deep, with most of heavy oils removed in the 0-20 cm surface layer, thus avoiding additional pollution of the deep soil layer. Furthermore, contaminated soils had beneficial impacts on soil physiochemical indices of chloride (Cl-), pH, and organic matter in the 0-20 cm surface layer, as well as allowing total nitrogen (TN) and total phosphorus (TP) in the 0-20 cm surface layer to recover within the last 2 years of operation. At the end of this experiment, all these indices in the soil profile (0-80 cm) followed the same trend as those in normal soil. During the first harvest season, reed biomass in the wetland increased with increasing heavy oil pollution loading. In the last two harvest seasons, reed biomass followed the same trend, i.e., at the highest and lowest contaminated soil levels (18 and 0.2 kg oil-polluted soil m-2 soil, respectively), reed biomass in reed beds increased with time, and resulted in levels higher than in the control. In contrast, at middle contaminated soil levels (2 and 6 kg oil-polluted soil m-2 soil) reed biomass followed an inverse trend similar to that experienced by the control. Reed health results suggested that contaminated soils had no obvious adverse effects on reed height and number of leaves, and no significant effect on the eco-physiological indices of reeds, including cellulose, pentose, lignose, length and width ratio of cellulose, and width of cellulose. There was also no effect on germination percentages from below-ground rhizomes, but some inhibition on the germination process. In order to analyze heavy oil uptake and distribution within reeds, a 14C-hexadecane tracer experiment was conducted in 2003. Results indicated that after a growing season, heavy oil concentrated mainly in the below-ground root of reeds.

Author Keywords
Bioremediation; Ecological risk; Heavy oil; Reed wetland

Document Type: Article
Source: Scopus

Khaitan, S.[a] , Kalainesan, S.[a] , Erickson, L.E.[a] , Kulakow, P.[b] , Martin, S.[c] , Karthikeyan, R.[d] , Hutchinson, S.L.L.[d] , Davis, L.C.[e] , Illangasekare, T.H.[f] , Ng'oma, C.[g]
Remediation of sites contaminated by oil refinery operations
(2006) *Environmental Progress*, 25 (1), pp. 20-31. Cited 1 time.

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[c] Center for Hazardous Substance Research, Kansas State University, Manhattan, KS 66506

[d] Department of Biological and Agricultural Engineering, Kansas State University, Manhattan, KS 66506
[e] Department of Biochemistry, Kansas State University, Manhattan, KS 66506
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[g] RETEC Group, Inc., Shawnee Mission, KS 66202

Abstract
The oil industry contributes to contamination of groundwater and aquifers beneath refineries and oil terminals. The successful remediation of a contaminated site requires understanding both the hydrogeology and the nature and extent of contamination. The physical chemical and biological mechanisms that govern contaminant release, transport and fate in soils, sediments, and associated fluid phases must be understood and quantified. In addition, understanding the flow and entrapment of nonaqueous phase liquids (NAPLs) including lighter-than-water non-aqueous phase liquids (LNAPLs) in contaminated aquifers is important for the effective design of the recovery and remediation schemes. Current remedial technologies and risk assessment techniques to remediate former oil refinery sites contaminated by NAPLs are described in this paper. Emphasis is given to the most promising remediation techniques such as pump-and-treat, on-site bioremediation, phytoremediation, in situ soil washing, and thermal-based technologies, such as steam-enhanced extraction. Some enhancements to pump-and-treat techniques such as solvent flushing, polymer enhanced flushing, and air stripping are also discussed. Finally, important risk-based cleanup criteria associated with contaminated soil at refineries are presented. © 2005 American Institute of Chemical Engineers.

Document Type: Article
Source: Scopus

Simon, M.A.[a c d] , Autenrieth, R.L.[a] , McDonald, T.J.[a] , Bonner, J.S.[b]
Evaluation of bioaugmentation for remediation of petroleum in a wetland
(2005) *2005 International Oil Spill Conference, IOSC 2005*, pp. 2729-2737.

[a] Civil Engineering Department, Texas A and M University, College Station, TX 77843-3136
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[c] Civil Engineering Department, Texas A and M University, College Station, TX
[d] San Jacinto Wetland Research Facility

Abstract
The primary goal of this research was to evaluate the performance of two commercial bioaugmentation products for their ability to enhance bioremediation of petroleum in a wetland. Additional treatments included inorganic nutrients. and an oiled control (intrinsic). The experiment used a controlled application of oil to reduce heterogeneity normally associated with spilled petroleum. The experimental design incorporated full replication and interspersion of treatments in a block design. The first-order biodegradation rate coefficients for the total target saturate and total target aromatic hydrocarbons showed no significant differences between

treatments. Comparison of first-order biodegradation rate coefficients for individual hydrocarbon target analytes also showed no differences between the treatments. Although not statistically significant, one of the commercial bioaugmentation products did show consistently higher biodegradation rates for individual target analytes. Comparison of first-order biodegradation rate coefficients for the control treatment showed biodegradation rates comparable with those obtained in previous studies conducted at the site. This research study and the previous studies conducted at the site demonstrate bioremediation can be effective in removing petroleum from the environment. However, further research is necessary to optimize treatment strategies and to increase the understanding of the processes that contribute to bioremediation of petroleum in a wetland.

Document Type: Conference Paper
Source: Scopus

Mendelssohn, I.A.[a] , Lin, Q.[a] , Debusschere, K.[b] , Henry Jr., C.B.[c] , Overton, E.B.[c] , Portier, R.J.[c] , Walsh, M.M.[c] , Penland, S.[d] , Rabalais, N.N.[e]
The development of bioremediation for oil spill cleanup in coastal wetlands: Product impacts and bioremediation potential
(2005) *2005 International Oil Spill Conference, IOSC 2005*, pp. 1848-1857.

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[c] Institute for Environmental Studies, Center for Coastal, Energy and Environmental Resources, Louisiana State University, Baton Rouge, LA 70803
[d] Coastal Studies Institute, Center for Coastal, Energy and Environmental Resources, Louisiana State University, Baton Rouge, LA 70803
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Abstract
Although bioremediation for oil spill cleanup has received considerable attention in recent year, its satisfactory use in the cleanup of oil spills in the wetland environment is still questionable and generally untested. We have initiated a multidisciplinary experimental program to evaluate the use of both microbial seeding and fertilizer as means of enhancing oil biodegradation in coastal salt marshes. We are utilizing controlled greenhouse experiments as well as field trials to test the efficacy and ecological safety of these enhanced biodegradation methodologies. This paper summarizes the overall scope of the study and presents some preliminary findings concerning marsh plant response to the bioremediation agents. we shall report on the results of the first year of this three-year investigation. Sods of marsh (soil and vegetation intact), approximately 30 cm in diameter and 25 cm deep, collected from the inland zone of a Spartina alterniflora dominated salt marsh in south Louisiana were used in a greenhouse experiment to identify the effects on plant and soil responses of the following treatments, with and without oil: seeding product, fertilizer product, and control (no product). Mesocosms were sampled for petroleum hydrocarbon chemistry to identify and quantify the degree of oil biodegradation, soil microbial response to determine the effect of the bioremediation products on the microbial communities that are

performing the oil biodegradation, soil chemistry to determine the effect of the bioremediation products (such as nutrients, soil reducing conditions, and soil toxins) on those factors that limit the growth of microbes and plants and plant response to evaluate the effects of the oil and products on plant vigor and growth. This paper presents selected plant responses that demonstrated that the bioremediation products tested had no adverse impact on plant growth. additionally,soil respiration was increased by fertilizer, but not microbial, application.

Document Type: Conference Paper
Source: Scopus

Stephens, F.L.[a] , Pirnie, M.[a] , Bonner, J.S.[b] , Autenrieth, R.L.[c] , McDonald, T.J.[c]
TLC/FID analysis of compositional hydrocarbon changes associated with bioremediation
(2005) *2005 International Oil Spill Conference, IOSC 2005*, pp. 8432-8439.

[b] Conrad Blucher Institute, Corpus Christi, TX
[c] Texas A and M University, College Station, TX

Abstract
Petroleum released into the environment is subjected to numerous biotic and abiotic processes. Monitoring the losses caused by these varying processes is important in order to reliably assess the effectiveness of natural attenuation versus remediation techniques. Traditional methods of characterising and monitoring oil from spills generate either a gross measurement or a very specific measurement of petroleum components. The latroscan thin layer chromatography (TLC) flame ionization detection (FID) system represents an analysis that performs quantitative gross compositional analysis of oil samples. The latroscan TLC/FID system measures the relative percentages of the four major fractions of petroleum; saturate, aromatic, resin, and asphaltene. Measurement of these petroleum fractions over time allows for the evaluation of compositional changes due to weathering and degradation processes. The objective of this study was to demonstrate the effectiveness of the TLC/FID system as a tool to monitor changes in petroleum composition from environmental processes. Results of the experiment showed an initial rapid decrease in the compositional saturate and aromatic fractions coinciding with an increase in the resin fraction. The asphaltene content remained relatively constant throughout the project.

Document Type: Conference Paper
Source: Scopus

Williams, G.W.[a e] , Gondek, R.[b] , Allen, A.A.[c] , Michel, J.[d]
Use of in situ burning at a diesel spill in wetlands and salt flats, Northern Utah, U.S.A: Remediation operations and 1.5 years of post-burn monitoring
(2005) *2005 International Oil Spill Conference, IOSC 2005*, pp. 9544-9548.

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[b] ChevronTexaco Pipe Line Company, 2811 Hayes Road, Houston TX 77082, United States
[c] Spiltec, 19220 N.E. 143rd Place, Woodinville, WA 98072, United States
[d] Research Planning, Inc., 1121 Park Street, Columbia, SC 29201, United States
[e] EarthFax Engineering, Inc., Salt Lake City, UT

Abstract
On 21 January 2000, a release of an estimated 100 barrels of diesel was reported from a product transportation pipeline north of Great Salt Lake in Utah. During the next few days, due to weather related conditions (freeze/thaw periods and wind), the product spread over 38 acres of salt flat and wetlands. Initial oil containment efforts were successful in reducing the risk of oil impacts to natural resources in a nearby national migratory bird refuge, but the risk remained to migratory waterfowl that were expected to arrive at the impacted wetland within approximately 6 weeks. As a result, in situ burning was proposed to remove the free-phase diesel and destroy the hydrocarbon-impacted vegetation. Upon approval of a Site Remediation Plan and Fire Management Plan, a Heli-Torch was used on 10 March, 2000 to burn the most-highly impacted 12.8 acres. The following month (late-April), 3.2 acres of remaining lightly oiled vegetation were burned using drip torches and propane wands. It was estimated that 75- 80% of the spilled diesel was burned in these operations. Because burning of the free-phase hydrocarbons and impacted vegetation would not remove product that had penetrated into the soils, bioremediation techniques were subsequently implemented, in order to further reduce hydrocarbon levels in the soil and attain the regulatory cleanup level of 20 mg/kg total polycyclic aromatic hydrocarbons.

Document Type: Conference Paper
Source: Scopus

Gessner, T.P.[a] , Kadlec, R.H.[b] , Reaves, R.P.[c]
Wetland remediation of cyanide and hydrocarbons
(2005) *Ecological Engineering*, 25 (4), pp. 457-469. Cited 1 time.

[a] BHE Environmental Inc., 11733 Chesterdale Road, Cincinnati, OH 45246, United States
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[c] CH2M HILL 115 Perimeter Center Place NE, Atlanta, GA 30346, United States

Abstract
Cyanide is a common constituent present in groundwater from historical aluminum industry landfills. Aluminum manufacturing produces wastes which contain cyanide, together with fluoride, a variety of metals, and some petroleum hydrocarbons. These leachates pose a moderate threat to receiving ecosystems and human health. Source control is virtually impossible, and physico-chemical removal processes are expensive and energy intensive. This pilot project investigated the

use of free water surface wetlands for the reduction of complex and free cyanide and associated pollutants in water from a groundwater spring. Shallow basins, initially planted with cattail (Typha latifolia) and bulrush (Schoenoplectus tabernaemontani), subsequently converted to coontail (Ceratophyllum demersum) and pondweed (Potamageton spp.). Both total and free cyanide were effectively reduced during 7 d detention, by 56% and 88%, respectively. Gasoline range organics and diesel range organics were reduced by approximately 67%. These removals are lower bound estimates, because effluent concentrations were often below detection. First order areal removal rate constants were in the range 13-100 m/year for the various constituents. Preliminary, synoptic studies indicated little volatilization of the cyanide, but significant microbial degradation, and essentially no harmful by-products. The full-scale treatment wetland is entering the final design stages and is scheduled for construction in 2004.

Author Keywords
Cyanide; Groundwater; Hydrocarbons; Remediation; Treatment wetlands

Document Type: Article
Source: Scopus

Lin, Q.[a] , Mendelssohn, I.A.[a] , Carney, K.[b] , Miles, S.M.[b] , Bryner, N.P.[c] , Walton, W.D.[c]

In-situ burning of oil in coastal marshes. 2. Oil spill cleanup efficiency as a function of oil type, marsh type, and water depth

(2005) *Environmental Science and Technology*, 39 (6), pp. 1855-1860. Cited 2 times.

[a] Wetland Biogeochemistry Institute, School of the Coast and Environment, Louisiana State University, Baton Rouge, LA 70803, United States
[b] Institute for Environmental Studies, School of the Coast and Environment, Louisiana State University, Baton Rouge, LA 70803, United States
[c] Natl. Inst. of Std. and Technology, U.S. Department of Commerce, Gaithersburg, MD 20899, United States

Abstract
In-situ burning of spilled oil, which receives considerable attention in marine conditions, could be an effective way to cleanup wetland oil spills. An experimental in-situ burn was conducted to study the effects of oil type, marsh type, and water depth on oil chemistry and oil removal efficiency from the water surface and sediment. In-situ burning decreased the total targeted alkanes and total targeted polycyclic aromatic hydrocarbons (PAHs) in the burn residues as compared to the pre-burn diesel and crude oils. Removal was even more effective for short-chain alkanes and low ring-number PAHs. Removal efficiencies for alkanes and PAHs were >98% in terms of mass balance although concentrations of some long-chain alkanes and high ring-number PAHs increased in the burn residue as compared to the pre-burn oils. Thus, in-situ burning potentially prevents floating oil from drifting into and contaminating adjacent habitats and penetrating the sediment. In addition, in-situ burning significantly removed diesel oil that had penetrated the sediment for

all water depths. Furthermore, in-situ burning at a water depth 2 cm below the soil surface significantly removed crude oil that had penetrated the sediment. As a result, in-situ burning may reduce the long-term impacts of oil on benthic organisms.

Document Type: Article
Source: Scopus

Murygina, V.P.[a] , Markarova, M.Y.[b] , Kalyuzhnyi, S.V.[a]
Application of biopreparation "Rhoder" for remediation of oil polluted polar marshy wetlands in Komi Republic
(2005) *Environment International*, 31 (2), pp. 163-166. Cited 6 times.

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[b] Inst. of Biol. Russ. Academy Science, Ural Division, Siktivkar, Komi Republic, Russian Federation

Abstract
This paper describes the testing and corresponding results of the preparation "Rhoder" in comparison with several other bioremediation variants during the field trials in Komi Republic throughout 2002-2003. All bioremediation trials were performed on one vast polar marshy wetland polluted by accidental crude oil spill and uncovered by grass. After application of the "Rhoder" at the site, with an area of □2000 m2, during the cold and rainy summer of 2002 (1.5 months), the level of oil contamination decreased by 20-51%, depending on initial oil pollution (458-738 g/kg dry weight of soil). In the middle of September 2002, the treated site was covered by 70-85% with green grass. Though, during 2003, the "Rhoder" treatment was not practiced, at the end of August 2003, the site was already covered by 85-95% with green grass and the level of oil contamination further decreased by 54-79% from the initial level of oil pollution at the beginning of 2002. These results were much better compared to those from other bioremediation variants applied at this spill.

Author Keywords
Bioremediation; Komi Republic; Oil polluted polar marshy wetland; Preparation "Rhoder"

Document Type: Conference Paper
Source: Scopus

Mills, M.A.[a c] , Bonner, J.S.[b] , Page, C.A.[b] , Autenrieth, R.L.[a]
Evaluation of bioremediation strategies of a controlled oil release in a wetland
(2004) *Marine Pollution Bulletin*, 49 (5-6), pp. 425-435. Cited 1 time.

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Station, TX, United States
[b] Conrad Blucher Inst. Surv. and Sci., Texas AandM Univ.-Corpus Christi, 6300 Ocean Drive, 78412, Corpus Christi, TX, United States
[c] US Environmental Protection Agency, Natl. Risk Mgmt. Research Laboratory, 26 W. Martin Luther King Dr., 45268, Cincinnati, OH, United States

Abstract
A controlled petroleum release was conducted to evaluate bioremediation in a wetland near Houston, Texas. The 140-day study was conducted using a randomized, complete block design to test three treatments with six replicates per treatment. The three treatment strategies were inorganic nutrients, inorganic nutrients with an alternative electron acceptor, and a no-action oiled control. Samples were analyzed for petroleum chemistry and inorganic nutrients. These results are discussed in the context of our related research involving toxicology and microbiology at the site during the experiment. To evaluate biodegradation, the targeted compounds were normalized to the conservative compound C3017α, 21β-[H]hopane, thus reducing the effects of spatial heterogeneity and physical transport. The two biostimulation treatments demonstrated statistically-higher rates of biodegradation than the oiled no-action control. For the majority of the experiment, target nutrient levels were maintained. Further research may be warranted to optimize these bioremediation strategies as well as evaluating additional treatment strategies for wetlands and other shoreline systems.

Author Keywords
Bioremediation; Biostimulation; Nutrients; Petroleum; Wetland

Document Type: Article
Source: Scopus

Khan, F.I.[a] , Husain, T.[a] , Hejazi, R.[a b]
An overview and analysis of site remediation technologies
(2004) *Journal of Environmental Management*, 71 (2), pp. 95-122. Cited 17 times.

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Abstract
This paper presents an analysis of the site restoration techniques that may be employed in a variety of contaminated site cleanup programs. It is recognized that no single specific technology may be considered as a panacea for all contaminated site problems. An easy-to-use summary of the analysis of the important parameters that will help in the selection and implementation of one or more appropriate technologies in a defined set of site and contaminant characteristics is also included.

Author Keywords

Groundwater cleanup; Natural attenuation; Site remediation; Soil remediation; Soil vapor extraction

Document Type: Review
Source: Scopus

Van Hamme, J.D.[a] , Singh, A.[b] , Ward, O.P.[c]

Recent Advances in Petroleum Microbiology

(2003) *Microbiology and Molecular Biology Reviews*, 67 (4), pp. 503-549. Cited 74 times.

[a] Department of Biological Sciences, University College of the Cariboo, Kamloops, BC V2C 5N3, Canada
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[c] Department of Biology, University of Waterloo, Waterloo, Ont. N2L 3G1, Canada

Abstract
Recent advances in molecular biology have extended our understanding of the metabolic processes related to microbial transformation of petroleum hydrocarbons. The physiological responses of microorganisms to the presence of hydrocarbons, including cell surface alterations and adaptive mechanisms for uptake and efflux of these substrates, have been characterized. New molecular techniques have enhanced our ability to investigate the dynamics of microbial communities in petroleum-impacted ecosystems. By establishing conditions which maximize rates and extents of microbial growth, hydrocarbon access, and transformation, highly accelerated and bioreactor-based petroleum waste degradation processes have been implemented. Biofilters capable of removing and biodegrading volatile petroleum contaminants in air streams with short substrate-microbe contact times (<60 s) are being used effectively. Microbes are being injected into partially spent petroleum reservoirs to enhance oil recovery. However, these microbial processes have not exhibited consistent and effective performance, primarily because of our inability to control conditions in the subsurface environment. Microbes may be exploited to break stable oilfield emulsions to produce pipeline quality oil. There is interest in replacing physical oil desulfurization processes with biodesulfurization methods through promotion of selective sulfur removal without degradation of associated carbon moieties. However, since microbes require an environment containing some water, a two-phase oil-water system must be established to optimize contact between the microbes and the hydrocarbon, and such an emulsion is not easily created with viscous crude oil. This challenge may be circumvented by application of the technology to more refined gasoline and diesel substrates, where aqueous-hydrocarbon emulsions are more easily generated. Molecular approaches are being used to broaden the substrate specificity and increase the rates and extents of desulfurization. Bacterial processes are being commercialized for removal of H_2S and sulfoxides from petrochemical waste streams. Microbes also have potential for use in removal of nitrogen from crude oil leading to reduced nitric oxide emissions provided that technical problems similar to those experienced in biodesulfurization can be solved. Enzymes are being exploited to produce added-value products from petroleum substrates, and bacterial biosensors are being used to analyze petroleum-contaminated environments.

Document Type: Review
Source: Scopus

Filler, D.M.[a b] , Barnes, D.L.[b]

Technical procedures for recovery and evaluation of chemical spills on tundra

(2003) *Cold Regions Science and Technology*, 37 (2), pp. 121-135.

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Abstract
Prior to the Exxon Valdez oil spill in 1989, arctic and subarctic spill response was in its infancy, and documented research into the environmental consequences of terrestrial spills in cold regions was scarce. Spills to tundra most often result from oil exploration and pipeline transport of fuels, the preponderance of documented spills having been crude oil and refined petroleum products, and the occasional spill of saline water or synthetic fluids. In their present state, North American tundra treatment guidelines generally describe the response and cleanup methods applicable to petroleum-related spills; adequate recovery methods for acid-mixture spills on tundra have not been developed. This paper describes the lessons learned from an acid/xylene spill that occurred in the central Arctic Coastal Plain of Alaska (North Slope) in October 2001. Recovery (response and cleanup) methods are developed and site characterization is discussed with consideration for sampling and analysis plan design, potential problems with standard analytical testing methods, and an alternative approach to assessing contamination in frozen ground.

Author Keywords
Arctic; Spills; Tundra

Document Type: Article
Source: Scopus

Mueller, D.C.[a] , Bonner, J.S.[b] , McDonald, S.J.[c] , Autenrieth, R.L.[a] , Donnelly, K.C.[d] , Lee, K.[e] , Doe, K.[f] , Anderson, J.[g]

The use of toxicity bioassays to monitor the recovery of oiled wetland sediments

(2003) *Environmental Toxicology and Chemistry*, 22 (9), pp. 1945-1955. Cited 5 times.

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Drive, Corpus Christi, TX 78412, United States
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[e] Ctr. Offshore Oil/Gas Environ. Res., Fisheries and Oceans Canada, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, NS B2Y 4A2, Canada
[f] Environmental Sciences Centre, Environment Canada, Moncton, NB E1A 3E9, Canada
[g] Columbia Analytical Sciences, 6060 Corte del Cedro, Carlsbad, CA 92009-1514, United States

Abstract
Six toxicity assays were compared to determine their efficacy in assessing toxicity dynamics during a wetland bioremediation study. The toxicity bioassays used were the Microtox® 100% elutriate test, Microtox Solid Phase Test (SPT), amphipod assay, P450 reporter gene system, Toxi-ChromoPad™ test and a Salmonella/microsome assay. Oiled sediments were analyzed for toxicity in the petroleum biostimulation experiment conducted along the San Jacinto River, near Houston (TX, USA). The bioassays were evaluated for their ability to measure acute toxicity, chronic toxicity, and the mutagenic potential of amended oiled plots as compared to oiled and unoiled control plots. Amendments were diammonium phosphate alone or in combination with potassium nitrate, which served as an alternate electron acceptor. With exception of the Toxi-ChromoPad and Salmonella tests, the bioassays exhibited a significant increase in toxicity after oil application. Microtox bioassays detected significant sediment toxicity up to 29 d after oil and amendment application. The Microtox solid phase test results correlated strongly with gas chromatography-mass spectrometry analyses of total target saturate and aromatic hydrocarbons. The amphipod assay detected initial toxicity with a decline to day 70, followed by a significant increase in toxicity on day 140 in plots receiving nutrient amendments, which may be in response to excessive nutrient application. Low levels of enzyme induction were observed with the P450 reporter gene system assay in all oiled sediments throughout the study, suggesting low but persistent levels of polycyclic aromatic hydrocarbons. Of the six tests, the two Microtox tests and the amphipod test showed the most potential in evaluating petroleum toxicity in wetland sediments.

Author Keywords
Bioremediation; Microbial/amphipod bioassays; Mutagenicity; Petroleum; Sediments

Document Type: Article
Source: Scopus

Lindau, C.W., Delaune, R.D., Jugsujinda, A.
Marsh sensitivity to burning of applied crude oil
(2003) *Spill Science and Technology Bulletin*, 8 (4), pp. 401-404.

Dept. of Oceanography/Coastal Sci., Wetland Biogeochemistry Institute, Louisiana State University, Baton Rouge, LA 70803-7511, United States

Abstract
This research note summarizes Spartina alterniflora and Sagittaria lancifolia sensitivity to oiling and in situ burning of applied oil. Experimental plots (2.4 × 2.4 m × 0.6 m) were constructed in salt and freshwater marsh habitats and South Louisiana Crude (SLC) applied (2 l m-2) to stems and leaves of marsh plants of oil and oil/burn treatment plots. Burning was initiated mid-August when winds were calm and a 15-25 cm floodwater layer covered the marsh substrate. Vegetative responses (stem density, height, carbon assimilation and biomass production) were measured for approximately one year following the in situ burns. Application of oil and burning of SLC only had short-term detrimental effects on salt and freshwater marsh vegetation. About one year after burns, vegetative responses measured in oiled and oiled/burned plots approached or exceeded control (no oil or burn) values. Field results suggest, under our experimental conditions, in situ burning of spilled oil in S. alterniflora and S. lancifolia marshes may be a remediation operation to consider.

Author Keywords
Coastal marshes; Crude oil; In situ burning; Oil spill

Document Type: Article
Source: Scopus

Mills, M.A.[a c] , Bonner, J.S.[b] , McDonald, T.J.[b] , Page, C.A.[b] , Autenrieth, R.L.[a]
Intrinsic bioremediation of a petroleum-impacted wetland
(2003) *Marine Pollution Bulletin*, 46 (7), pp. 887-899. Cited 11 times.

[a] Department of Civil Engineering, Texas A and M University, College Station, TX 77843, United States
[b] Conrad Blucher Inst. for Surv./Sci., TX A/M University - Corpus Christi, Corpus Christi, TX 78412, United States
[c] US Environmental Protection Agency, Natl. Risk Mgmt. Research Laboratory, Cincinnati, OH 45268, United States

Abstract
Following the 1994 San Jacinto River flood and oil spill in southeast Texas, a petroleum-contaminated wetland was reserved for a long-term research program to evaluate bioremediation as a viable spill response tool. The first phase of this program, presented in this paper, evaluated the intrinsic biodegradation of petroleum in the contaminated wetland. Sediment samples from six test plots were collected 11 times over an 11-month period to assess the temporal and spatial petroleum concentrations. Petroleum concentrations were evaluated using gas chromatography-mass spectrometer analyses of specific target compounds normalized to the conservative biological marker, C 3017α,21β(H)-hopane. The analyses of specific target compounds were able to characterize that significant petroleum biodegradation had occurred at the site over the one-year period. Total resolved saturate and total resolved aromatic hydrocarbon data indicated the petroleum was degraded more than 95%. In addition, first-order biodegradation rate constants were calculated for the hopane-normalized target compounds and

supported expected biodegradation patterns. The rapid degradation rates of the petroleum hydrocarbons are attributed to conditions favorable to biodegradation. Elevated nutrient levels from the flood deposition and the unconsolidated nature of the freshly deposited sediment possibly provided a nutrient rich, oxic environment. Additionally, it is suggested that an active and capable microbial community was present due to prior exposure to petroleum. These factors provided an environment conducive for the rapid bioremediation of the petroleum in the contaminated wetland.

Author Keywords
Bioremediation; Hydrocarbons; Intrinsic remediation; Natural attenuation; Petroleum; Wetland

Document Type: Article
Source: Scopus

Venosa, A.D.[a] , Zhu, X.[b]
Biodegradation of crude oil contaminating marine shorelines and freshwater wetlands
(2003) *Spill Science and Technology Bulletin*, 8 (2), pp. 163-178. Cited 9 times.

[a] Natl. Risk Management Res. Lab., US Environmental Protection Agency, 26 W. Martin Luther King Dr., Cincinnati, OH 45268, United States
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Abstract
This paper is a summary of the various factors influencing weathering of oil after it has been released into the environment from a spill incident. Special emphasis has been placed on biodegradation processes. Results from two field studies conducted in 1994 and 1999 involving bioremediation of an experimental oil spill on a marine sandy shoreline in Delaware and a freshwater wetland on the St. Lawrence River in Quebec, Canada have been presented in the paper. Published by Elsevier Science Ltd.

Author Keywords
Biodegradation; Bioremediation; Contamination; Crude oil; Shorelines; Weathering; Wetlands

Document Type: Article
Source: Scopus

Legrand, R.[a] , Conwell, P.[b] , Pettigrew Jr., R.J.[b] , Tsao, D.[c]
Refinery Waste Stream Remediation Using Phytoremediation
(2002) *NPRA Annual Meeting Papers*, 2002, 12 p.

[a] URS, Austin, United States

[b] URS, Houston, United States
[c] BP Corporation

Abstract
The results of the phytoremediation study conducted at the BP Amoco Land Treatment facility in Texas City, TX, since March 1999 were presented. Two studied plots were planted with a custom seed mixture (design vegetation); two others were allowed to revegetate naturally; and two control plots were routinely tilted to prevent vegetation growth. Oil and grease (O&G) concentrations in the 18-24-in BGS interval of the homogenized soil columns in the vegetated plots were significantly lower than in the control plots during the first year of the study. Phytoremediation was more cost-effective than tiling and created a natural habitat. The presence of undegraded hydrocarbons in the soils beneath the tlled zone of closed treatment cells C-4 and B-7, which extends to ≈ 12 in BGS, did not prevent the establishment of vegetation. Of the five ground cover plant species introduced into the DSV plots, prairie switch grass (Panicum virgatum) as the most capable of thriving at the LTF and competing with volunteer species. Hydrocarbons leached from the surrounding undisturbed, fine-grained waste material into the coarser soil in the homogenized soil columns during the wet spring months. Sample collected from outside the homogenized soil columns during 2001 indicated that O&G concentration in the vegetated plots and in the CTL plots were similar for both the 18- to 24-in. BGS and 30- to-36-in. BGS intervals.

Document Type: Conference Paper
Source: Scopus

Venosa, A.D.[a] , Lee, K.[b] , Suidan, M.T.[c] , Garcia-Blanco, S.[c] , Cobanli, S.[d] , Moteleb, M.[c] , Haines, J.R.[a] , Tremblay, G.[b] , Hazelwood, M.[d]
Bioremediation and biorestoration of a crude oil-contaminated freshwater wetland on the St. Lawrence River
(2002) *Bioremediation Journal*, 6 (3), pp. 261, 279. Cited 9 times.

[a] U.S. Environmental Protection Agency, Natl. Risk Mgmt. Research Laboratory, Cincinnati, OH 45268, United States
[b] Bedford I. O. Fish./Oceans-Canada, Dartmouth, NS B2Y 4A2, Canada
[c] Dept. of Civ./Environmental Eng., University of Cincinnati, Cincinnati, OH 45221, United States
[d] BDR Research, Halifax, NS, Canada

Abstract
Biostimulation by nutrient enrichment and phytoremediation were studied for the restoration of an acutely stressed freshwater wetland experimentally exposed to crude oil. The research was carried out along the shores of the St. Lawrence River at Ste. Croix, Quebec. Canada. The effectiveness of fertilizer addition in enhancing the biodegradation rates of residual oil was determined. The rate at which the stressed ecosystem recovered with and without the addition of inorganic fertilizers and the role of nutrients in enhancing wetland restoration in the absence of healthy wetland plants were examined. Chemical analysis of integrated sediment core samples to the depth of oil penetration within the experimental plots indicated that

addition of inorganic nutrients did not enhance the disappearance of alkanes or PAH. In surface samples, however, hydrocarbon disappearance races were higher when the metabolic activity of wetland plants was suppressed by the removal of emergent plant growth. The results suggested that oxygen limitation plays a major role in preventing rapid biodegradation of hydrocarbons in anoxic wetland sediment.

Author Keywords
Alkanes; Biodegradation; Bioremediation; Biostimulation; Crude oil; Freshwater wetlands; Hydrocarbons; MPNs; Nitrogen; Nutrient enrichment; Nutrients; PAHs; Phosphorus; Phytoremediation

Document Type: Article
Source: Scopus

Williams, J.B.
Phytoremediation in wetland ecosystems: Progress, problems, and potential
(2002) *Critical Reviews in Plant Sciences*, 21 (6), pp. 607-635. Cited 18 times.

Department of Biological Sciences, South Carolina State University, Orangeburg, SC 29117, United States

Abstract
Assessing the phytoremediation potential of wetlands is complex due to variable conditions of hydrology, soil/sediment types, plant species diversity, growing season, and water chemistry. Conclusions about long-term phytoremediation potential are further complicated by the process of ecological succession in wetlands. This review of wetlands phytoremediation addresses the role of wetland plants in reducing contaminant loads in water and sediments, including metals; volatile organic compounds (VOC), pesticides, and other organohalogens; TNT and other explosives; and petroleum hydrocarbons and additives. The review focuses on natural wetland conditions and does not attempt to review constructed wetland technologies. Physico-chemical properties of wetlands provide many positive attributes for remediating contaminants. The expansive rhizosphere of wetland herbaceous shrub and tree species provides an enriched culture zone for microbes involved in degradation. Redox conditions in most wetland soil/sediment zones enhance degradation pathways requiring reducing conditions. However, heterogeneity complicates generalizations within and between systems. Wetland phytoremediation studies have mainly involved laboratory microcosm and mesocosm technologies, with the exception of planted poplar communities. Fewer large-scale field studies have addressed remediation actions by natural wetland communities. Laboratory findings are encouraging with regards to phytoextraction and degradation by rhizosphere and plant tissue enzymes. However, the next phase in advancing the acceptance of phytoremediation as a regulatory alternative must demonstrate sustained contaminant removal by intact natural wetland ecosystems.

Author Keywords
Degradation; Heavy metals; Monitoring; Phytovolatilization; Succession; TCE

Document Type: Review
Source: Scopus

Ghaly, A.E., Pyke, J.B.
In-vessel bioremediation of oil-contaminated peat
(2001) *Energy Sources*, 23 (4), pp. 305-325. Cited 1 time.

Biological Engineering Department, Dalhousie University, P.O. Box 1000, Halifax, NS B3J 2X4, Canada

Abstract
Petroleum pollution of the ocean arises from activities undertaken to meet energy requirements such as extraction, transport, and general uses of petroleum products. Marine transport of oil has greatly increased over the past few decades and oil spills affect the living and non-living resources of the surrounding areas. In this study, the effectiveness of peat in the remediation of oil contaminated water was tested and the in-vessel bioremediation of the oil contaminated peat was evaluated. The results indicated that kiln dried peat is an excellent absorbent for extracting oil from water. It has the ability to remove 99.998% of the oil from contaminated water having an oil slick of 1.3 cm in depth. Mixing the peat with the contaminated water allowed for the coagulation of the peat with oil, and thus increased the oil removal efficiency, but also increased the moisture content of the peat. Evidence of three microbial populations (psychrophilic, mesophilic and thermophilic) in the bioreactor demonstrated the potential of the in-vessel bioremediation process to achieve a much higher oil degradation efficiency at a lower cost compared to biopiling and lasd farming. The worming of the material in the bioreactor and the increased moisture content were signs of the conversion of complex organic carbon by these microbes into energy, $CO2$ and $H2O$. Higher temperatures caused by mesophilic and thermophilic activities resulted in a higher conversion rate. The moisture content, pH and the aeration rate were within the optimum range for the bioremediation process. The poultry manure provided all the required nutrients for microbial growth, but nitrogen appeared to be the limiting factor. The bioremediation process achieved 56.7% reduction in oil content in about twelve days. Addition of a nitrogen source would have resulted in a much higher reduction percentage. The original humic mixture was reduced to a denser, but porous material that looked like a garden soil with a dark brown color and no oil odor. Copyright © 2001 Taylor & Francis.

Author Keywords
Absorption; Air; Contamination; In-vessel bioremediation; Micronutrient; Moisture content; Oil; Peat; Petroleum hydrocarbon; pH; Temperature; Water

Document Type: Article
Source: Scopus

Lee, K.[a] , Wohlgeschaffen, G.[a] , Cobanli, S.E.[a] , Gauthier, J.[a] , Doe, K.G.[b] , Jackman, P.M.[b] , Venosa, A.D.[c] , Lee, L.E.J.[d] , Suidan, M.T.[e] , Garcia-Blanco, S.[e]
Monitoring habitat recovery and toxicity reduction in an oiled freshwater wetland to determine remediation success
(2001) *Environment Canada Arctic and Marine Oil Spill Program Technical Seminar (AMOP) Proceedings*, 24, pp. 195-210. Cited 1 time.

[a] Mar. Environmental Sciences Division, Maurice Lamontagne Institute, Fisheries and Oceans Canada, Mont-Joli, QC, Canada
[b] Environmental Science Center, Environment Canada, Moncton, NB, Canada
[c] National Risk Management, Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH, United States
[d] Department of Biology, Wilfrid Laurier University, Waterloo, ON, Canada
[e] Department of Civil Engineering, University of Cincinnati, Cincinnati, OH, United States

Abstract
A controlled oil spill experiment was performed in a tidal freshwater marsh located along the St. Lawrence River, Canada. A weathered light crude oil (Mesa) was applied on 16 of 20 replicate experimental plots (5 × 4 m) at the rate of 12 L/plot. Remediation strategies under evaluation included: natural attenuation (no treatment); nutrient amendment with granular ammonium nitrate and super triple phosphate; an identical treatment with plants continuously cut back (to evaluate the effect of plant growth on remediation); and nutrient amendment with sodium nitrate and super triple phosphate. Physical and biological processes removed residual hydrocarbon components. In terms of observed habitat recovery, the dominant plant species (Scirpus pungens) was tolerant to the oil, and its growth was stimulated by the addition of nutrients. The only oiled treatment that gave a higher percentage survival after 30 days exposure was the ammonium nitrate amended plots with intact plants. This is an abstract of a paper presented at the 24th Arctic and Marine Oilspill Program Technical Seminar (Edmonton, Alberta 6/12-14/2001).

Document Type: Conference Paper
Source: Scopus

Pichtel, J., Liskanen, P.
Degradation of diesel fuel in rhizosphere soil
(2001) *Environmental Engineering Science*, 18 (3), pp. 145-157. Cited 9 times.

Ball State University, Dept. of Nat. Rsrc./Environ. Mgmt., Muncie, IN 47306-0495, United States

Abstract
Little is known regarding the ability of the plant rhizosphere to decompose diesel range organic (DRO) compounds in soil. A growth chamber study was conducted to assess the decomposition of DROs in soil as affected by grasses and legumes. A sandy loam soil was contaminated with 2% (w/w) commercial diesel fuel, and was treated with: (a) mixed NPK fertilizer; (b) urea; (c) glucose; and (d) control (i.e.,

no additives). Soil was seeded with either a grass mix (Poa, Phleum, Agrostis), a legume mix (Pisum sativum, Trifolium pratense); or no vegetation; and incubated. Over 150 days, approximately 10.6% of DROs was lost by volatilization. There was a trend toward decomposition of certain long-chain aliphatics in several treatments. DROs decreased most rapidly with the NPK fertilizer, regardless of plant cover. DRO concentrations were consistently lower under legumes compared to the other crop treatments, regardless of fertilizer treatment. The glucose treatment had lowest DRO reductions, presumably due to preferential utilization of the glucose over the aliphatics by micro-organisms. There was no detectable uptake of DROs by either grasses or legumes. Microbial counts increased under both grasses and legumes, but were not significantly ($p < 0.05$) different from counts in unvegetated soils.

Author Keywords
Diesel; DROs; Fertilizer; Glucose; Phytoremediation; Urea

Document Type: Article
Source: Scopus

Hutchinson, S.L., Banks, M.K., Schwab, A.P.
Phytoremediation of aged petroleum sludge: Effect of inorganic fertilizer
(2001) *Journal of Environmental Quality*, 30 (2), pp. 395-403. Cited 40 times.

Kansas State Univ., 147 Seaton Hall, Manhattan, KS 66507, United States

Abstract
Phytoremediation is a promising new technology that uses higher plants to enhance biodegradation. Nutrient availability is an important factor governing the success of phytoremediation and can be regulated through the addition of fertilizer. A greenhouse study was conducted to assess the importance of nitrogen and phosphorus for the phytoremediation of petroleum sludge. Degradation of total petroleum hydrocarbons (TPH) was quantified for six fertilization rates and three vegetation treatments: bermuda grass [Cynodon dactylon (L.) Pets.], tall fescue (Festuca arundinacea Schreb.), and an unvegetated control. During the first 6 mo of the experiment, TPH declined by an average of 49% with no significant differences between treatments. After 1 yr, TPH degradation was significantly greater in both vegetated treatments with a mean TPH reduction of 68% for bermuda, 62% for fescue, and 57% for the unvegetated control. Degradation of TPH in the fescue and bermuda treatments was significantly lower in the treatments in which no fertilizer was added or N and P were added simply to maintain plant growth compared with the higher rates of fertilization. For this short-term, greenhouse experiment, optimal remediation was obtained by fertilization that produced a C to N to P ratio of 100:2:0.2.

Document Type: Article
Source: Scopus

Lytle, J.S., Lytle, T.F.
Use of plants for toxicity assessment of estuarine ecosystems
(2001) *Environmental Toxicology and Chemistry*, 20 (1), pp. 68-83. Cited 26 times.

University of Southern Mississippi, Department of Coastal Sciences, Gulf Coast Research Laboratory, Ocean Springs, MS 39564, United States

Abstract
Estuarine ecosystems are being rapidly degraded by environmental toxicants from municipal and industrial wastes, agricultural runoff, recreational boating, shipping, and coastal development, ranking them as the most anthropogenically degraded habitat types on earth. Toxicity tests are used to establish links between adverse ecological effects and the toxicity of environmental chemicals. However, most toxicity tests used for regulating the release of chemicals into the environment have used animals as test species, with the erroneous assumption that toxicant levels protective of fish or invertebrates are also protective of plants. Most plant toxicity tests have used terrestrial crop plants, whereas the few aquatic test species used have been primarily freshwater algae. Even though estuarine and marine vascular plants are highly vulnerable to environmental chemicals, phytotoxicity studies using native coastal plants have been limited, and no such studies are required for testing by regulating agencies. The relevance of toxicity tests of estuarine sediments and of wastes entering the estuary should depend on the use of estuarine and marine plant species. This review summarizes toxicity testing of marine plants used in biomonitoring, phytotoxicity, biotransformations of toxicants, bioaccumulation, and phytoremediation. Challenges to marine plant testing are discussed and include developing standard test protocols, identifying species with minimal salinity and toxicant interaction, defining and choosing a suitable sediment for sediment-bound toxicant testing, selecting endpoints with low variability, producing viable seeds, and culturing test plants. Progress in acquiring a suitable database is being made, but at a rate that is inadequate to create the sound, scientific foundation needed for safeguarding our estuarine ecosystems in the near future.

Author Keywords
Biomonitors; Estuarine plants; Marine plants; Phytoremediation; Phytotoxicity

Document Type: Review
Source: Scopus

Pezeshki, S.R.[a] , Hester, M.W.[b] , Lin, Q.[c] , Nyman, J.A.[d]
The effects of oil spill and clean-up on dominant US Gulf coast marsh macrophytes: A review
(2000) *Environmental Pollution*, 108 (2), pp. 129-139. Cited 22 times.

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[b] Department of Biological Sciences, Southeastern Louisiana University, Hammond, LA 70402, United States
[c] Wetland Biogeochemistry Institute, Louisiana State University, Baton Rouge, LA 70803, United States

[d] Department of Biology, Univ. Southwestern Louisiana, PO B., Lafayette, LA 70504, United States

Abstract
The objective of this review was to synthesize existing information regarding the effects of petroleum hydrocarbons on marsh macrophytes in a manner that will help guide research and improve spill-response efficiency. Petroleum hydrocarbons affect plants chemically and physically. Although plants sometime survive fouling by producing new leaves, even relatively non- toxic oils can stress or kill plants if oil physically prevents plant gas- exchange. Plant sensitivity to fouling varies among species and among populations within a species, age of the plant, and season of spill. Physical disturbance and compaction of vegetation and soil associated with clean-up activities following an oil spill appear to have detrimental effects on the US Gulf coast marshes. Other techniques, including the use of chemicals such as cleaners or bioremediation, may be necessary to address the problem. Clean-up may also be beneficial when timely removal prevents oil from migrating to more sensitive habitats. (C) 2000 Elsevier Science Ltd.

Author Keywords
Bioremediation; Coastal marshes; Oil clean-up; Oil spill; Plant stress; Pollution

Document Type: Article
Source: Scopus

Mills, M.A.[a b] , McDonald, T.J.[a] , Bonner, J.S.[a] , Simon, M.A.[a] , Autenrieth, R.L.[a]
Method for quantifying the fate of petroleum in the environment
(1999) *Chemosphere*, 39 (14), pp. 2563-2582. Cited 25 times.

[a] Texas A/M University, Department of Civil Engineering, College Station, TX 77843-3136, United States
[b] Oakridge Inst. for Sci. and Educ., United States Environ. Protect. Agy., Natl. Risk Mgt. Research Laboratory, 26 W. Martin Luther King Dr., Cincinnati, OH 45268, United States

Abstract
Petroleum is a complex mixture of a wide range of hydrocarbon and non-hydrocarbon compounds of various physical and chemical properties. In recent years, the research on the fate of petroleum in the environment has required analytical methods that can provide more detailed information on the components of petroleum than traditional standard methods. The analytical method presented for aqueous, sediment, and soil samples provides several levels of information on petroleum in the environment. The Total Extractable Materials (TEM) analysis provides a gross measure of petroleum in the environment using methylene chloride extraction and gravimetric analysis. Gross composition analysis separates the methylene chloride extract into a saturate hydrocarbon, an aromatic hydrocarbon, and a polar fraction each measured gravimetrically. In contrast, the target compound analysis provides a detailed measure by GC-MS of 62 specific compounds. Normalization to the conservative compound, 17α,21β-(H)Hopane, is incorporated into the method to reduce the effects of sample and site

heterogeneity. Quality control and quality assurance procedures are integral parts of these analyses to assure the validity of the resulting data. A sample data set from a biological augmentation product evaluation was used only to illustrate the interpretation of the petroleum chemistry. In this example, conclusions were dependent on the criteria for evaluating the fate of petroleum. As the product evaluation progressed through the petroleum chemistry method, the conclusion on the their effectiveness changed. Therefore, proper interpretation of the petroleum chemistry, which is dependent an the method, is necessary to correctly evaluate the fate of petroleum in the environment.

Author Keywords
Biodegradation; GC-MS; Hydrocarbon; Petroleum chemistry

Document Type: Article
Source: Scopus

White, K.D.[b] , Burken, J.G.[a]
Natural treatment and on-site processes
(1999) *Water Environment Research*, 71 (5), pp. 676-685. Cited 4 times.

[a] Department of Civil Engineering, University of Missouri, Rolla, MO, United States
[b] Department of Civil Engineering, University of South Alabama, Mobile, AL 36688, United States

Abstract
The natural treatment systems, which is divided into land-treatment, wetland, aquatic, onsite and small community, and phytoremediation systems, are discussed. This include the free water surface constructed wetlands, subsurface flow constructed wetlands, vertical flow constructed wetlands,ponds, floating aquatic plant systems, solar aquatic systems, small treatment systems, and in-ground disposals.

Document Type: Review
Source: Scopus

Nyman, J.A.
Effect of crude oil and chemical additives on metabolic activity of mixed microbial populations in fresh marsh soils
(1999) *Microbial Ecology*, 37 (2), pp. 152-162. Cited 26 times.

Department of Biology, University of Southwestern Louisiana, P.O. Box 42451, Lafayette, LA 70504-2451, United States

Abstract
Hydrocarbons increase abundance of hydrocarbon-degrading microorganisms, but also decrease microbial diversity. This could disrupt ecosystem dynamics by altering soil organic matter mineralization and resultant nutrient remineralization rates.

Crude oil, which is known to contain toxins and reduce microbial diversity, was hypothesized to reduce gross metabolic activity of mixed microbial populations in wetland soils. Soil respiration and Eh were compared, for 6 months, among microcosms containing marsh soils that differed in soil organic matter (Panicum hemitomon Shult. or Sagittaria lancifolia L. dominated marshes), crude oil (Arabian crude, Louisiana crude, or no oil), and additives (a cleaner, a dispersant, fertilizer, or no additive). No treatment slowed activity; instead, Louisiana plus fertilizer and all Arabian treatments temporarily accelerated activity. Additional C respired from oiled microcosms exceeded C added as crude oil by 1.4 to 3.5 times. Thus, much additional C originated from soil organic matter rather than crude oil. Crude oils temporarily lowered soil Eh, which is consistent with accelerated metabolism and demand for electron acceptors. The lack of inhibition observed at the community level does not necessarily indicate an absence of toxicity. Instead, tolerant species with metabolic versatility probably maintained activity. Stimulation probably resulted from removal of micronutrient limitation, rather than removal of grazing pressure or macronutrient limitation. Regardless, accelerated soil organic matter mineralization surely accelerated nutrient remineralization. This might explain some reports of crude oil stimulating plant growth. These results are not inconsistent with theoretical and experimental conclusions regarding effects of biodiversity on ecosystem stability and productivity, nor are they inconsistent with conclusions that crude oils contain components that are toxic to microbes, vegetation, and fauna. However, these data do indicate that crude oils also contain components that temporarily stimulate metabolic activity of surviving microbes.

Document Type: Article
Source: Scopus

Lin, Q., Mendelssohn, I.A.

The combined effects of phytoremediation and biostimulation in enhancing habitat restoration and oil degradation of petroleum contaminated wetlands

(1998) *Ecological Engineering*, 10 (3), pp. 263-274. Cited 29 times.

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Abstract

The combined effects of biostimulation and phytoremediation as a means of post-oil spill habitat restoration and enhancement of oil degradation in the soil water were evaluated. Marsh sods of Spartina alterniflora and Spartina patents were dosed with 0, 4, 8, 16 and 24 1 m-2 of south Louisiana crude oil in the greenhouse. Plants were killed at oil dosages of 8 1 m-2 in the growing season following oil application. Two years after application of the oil, S. alterniflora and S. patens individuals were transplanted into the oiled and unoiled sods. Fertilizer was applied 1 and 7 months after transplantation. Application of the fertilizer significantly increased biomass of the transplants within 6 months and regrowth biomass of the transplants 1 year after transplantation for both plant species. The residual oil in the soil did not significantly affect the biomass of the S. patens transplants compared with that in the no oil treatment, except at the highest oil level. However, regrowth biomass of the S. alterniflora transplants treated with fertilizer was significantly higher at all oil levels up to 250 mg g-1 than in the unoiled treatment, with or without fertilizer. The oil degradation rate in the soil was significantly enhanced by the application of fertilizer in conjunction with the presence of transplants. These results suggest that vegetative transplantation, when implemented with fertilization, can simultaneously restore oil contaminated wetlands and accelerate oil degradation in the soil.

Author Keywords
Biostimulation; Marshes; Oil spills; Phytoremediation; Restoration; Spartina

Document Type: Article
Source: Scopus

Auerbach, N.A., Walker, M.D., Walker, D.A.
Effects of roadside disturbance on substrate and vegetation properties in arctic tundra
(1997) *Ecological Applications*, 7 (1), pp. 218-235. Cited 25 times.

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Abstract
Tundra adjacent to the gravel Dalton Highway in northern Alaska was examined for effects of 15 yr of chronic road and road dust disturbance. Road effects at a nonacidic site (soil pH ≤ 5.0) and an acidic site (soil pH < 5.0) were compared to examine differential susceptibility. Overall, effects on vegetation were more pronounced in acidic tundra. Initial substrate pH appears to control the degree of response to disturbance by road and calcareous road dust. Soil at the acidic site is normally pH 4.0, whereas in the disturbed area next to the road soil pH was as high as 7.3 ± 0.07 (at 2 m from the road edge). Soils next to the road had lower nutrient levels, altered organic horizon depth, higher bulk density, and lower moisture. Effects on snowpack include both increased drifting in the lee of the road and earlier meltout near the road due to dust-induced change in albedo. Permafrost thaw was deeper next to the road at both sites, and potentially could affect road structure detrimentally. Vegetation biomass of most taxa was reduced near the road at both sites. Total aboveground biomass of nonacidic tundra ranged from 330.0 ± 34.72 g/m2 (mean ± 1 SE) at 2 m from the road to 690.7 ± 94.52 g/m2 at 100 m away from the road. Total biomass of acidic tundra ranged from 150.5 ± 16.60 g/m2 at 5 m from the road to 743.1 ± 168.98 g/m2 at 100 m from the road. Species richness in acidic tundra next to the road was less than half of that at 100 m away from the road. Community composition was altered most noticeably in acidic tundra. The moss Tomentypnum nitens, dominant in nonacidic arctic tussock tundra, was nearly equally abundant at all distances from the road at the nonacidic tundra site, whereas Sphagnum mosses, dominant in acidic low arctic tussock tundra, were virtually eliminated near the road at the acidic tundra site. Salix lanata was more abundant next to the road at the nonacidic site. Ordinations indicate that variation in vegetation cover is explained by distance from the road. Knowledge of differential effects of road construction and use, including the long-term effects of hydrological alterations and dust mobilization on local corridors, is

key information for planning development in areas of arctic tundra. Planned placement of roads in the future should consider the impact of such changes to sensitive (acidic) tundra areas in the Arctic.

Author Keywords
Alaska; Arctic tundra; Biomass; Disturbance; Dust; Ordination; Permafrost; Sphagnum; Trans-Alaska Pipeline; Tundra vegetation

Document Type: Article
Source: Scopus

Portier, Ralph J., Shane, Barbara S., Overton, Edward B., Irvin, T.Rick, Martin, John E.

Site remediation of contaminated wetlands. Chemical characterization, biotreatment, waste minimization, and rapid toxicity assay development

(1990) *Journal of Hazardous Materials*, 24 (2-3), pp. 299-300.

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Abstract
National attention has focussed on the need for feasible technologies to permit on-site remediation of hazardous waste sites. To address this need, we are developing a biodegradation-based hazardous waste site remediation system in which an innovative analytical technology, thermal chromatography-mass spectrometry (TC-MS), in concert with short term genotoxicity and teratogenicity assays is being used to monitor the progress of degradation of the wastes. The Pab Oil site, located near Abbeville, LA, has been chosen as the hazardous waste site for the study. This site was originally established to recycle oil from oil-based muds generated from numerous sources. A series of remediation tests using liquids/solids contact (LSC) reactors were conducted on produced water sludges similar to those at the Pab Oil site. Total organic carbon was reduced from 9,800 mg/kg dry weight to 321 mg/kg dry weight after 14 days in the reactors. Residuals are undergoing further remediation in a modified land farm approach. TC-MS analysis showed significant reductions of both aliphatic and asphaltine fractions. A new reactor for the suspension of up to 40 percent solids in an aqueous slurry, which is present at this site, has been designed to improve remediation kinetics and minimize upsets. Preliminary studies using polymer chelation of metals from standing water from the Pab Oil site, has shown that 74 to 97 percent of arsenic, chromium, nickel, and zinc were removed in a fixed bed reactor. Six microbial strains, including two isolated during a recent cruise in the Gulf of Mexico where deep ocean petroleum seep communities in the Green Canyon were explored, show great promise for anaerobic degradation of polyaromatic hydrocarbons/petroleum mixtures. Four toxicity assays have been validated to monitor the toxicity of the oil wastes during the bioremediation process.

Document Type: Article
Source: Scopus
