Chapter 2
Local Gain, Global Loss: The Environmental Cost of Action

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2.1 Introduction

Lower toxicity and less pollution is the goal of all soil remediation. We are willing to spend money and time to achieve this. And our action of treating the soil causes new pollution in its turn.

The gain is local (cleaner soil), and the environmental cost is most often global or regional (global warming, particle and other air emissions, biodiversity, etc.). Balancing cost and gain is complicated by these different scales. Besides, everyone does not realise that the environmental costs are there. But if we are aware of the existence of such costs, there is also the possibility of minimizing them by choosing low-impact treatment options and low-impact materials. An example is the use of cement instead of steel for funnel walls (Bayer and Finkel 2006).

This chapter aims to show ways to improve the environmental impact of soil remediation. We will discuss the merits of various treatment techniques from this perspective, and point to areas where the environmental performance may be improved. Two simple evaluation models are applied to a petrol filling station as an example of environmental cost assessment. We conclude with aspects to consider which will help readers to improve their own soil treatment actions. The environmental cost is often calculated using various life cycle assessment methods (LCA). Many of our conclusions are based on LCA and LCA-related reasoning. The LCA method and problems encountered while applying the LCA method to contaminated soil are discussed in detail by Suer et al. (2004), and will not be addressed here.

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2.2 Better and Worse Treatment Choices

Unfortunately there is no general list of treatments in order of environmental cost. The costs depend on too many site-specific factors. Treatments can be ranked for a specific site, and this has been done for a number of sites (Table 2.1). Each study has used a consistent method for comparing treatments for the chosen site, while the methods themselves differ for the different sites. The exception is ScanRail Consult (2000a), which uses one method for comparing different technologies on different sites. Some general conclusions about better and worse treatments can be drawn from these site-specific studies.

A brief description of the impacts of the alternative remediation methods considered in the evaluations presented in Table 2.1 is given in the sections which follow. Some remediation methods have not been included in the reviewed studies, for example phytoremediation and monitored natural attenuation. These require

Table 2.1 Comparison of treatment techniques by various LCA methods

Techniques considered	Lowest environmental cost	Important factors	Reference
1. Isolation	–	Land use	(Diamond et al. 1999)
2. Excavation and landfill		Soil quality	
3. Soil washing		Discharge of chemicals	
4. Vapour extraction			
5. In situ bioremediation			
6. No action			
1. Excavation and on site landfill	1	Energy consumption	(Volkwein et al. 1999)
2. Surface sealing with asphalt		Soil quality	
3. Excavation, soil washing, turning bed, thermal treatment and landfill			
1. Covering and isolation	1, 3	Energy consumption	(Vignes 1999)
2. Ex situ thermal treatment		Leakage of chemicals	
3. In situ anaerobic degradation			
4. In situ aerobic degradation			
5. No action			
1. Ex situ thermal treatment	–	Energy consumption	(Ribbenhed et al. 2002)
2. Ex situ bioslurry		Transport of soil	
3. Ex situ soil washing			
4. In situ electrodialysis			
1. Ex situ degradation	2, 3, 5	Production of iron and concrete	(ScanRail Consult et al. 2000 a, b)
2. In situ biosparging		Transport of soil	
3. In situ bioventilation		Use of backfill	

(continued)

Table 2.1 (continued)

Techniques considered	Lowest environmental cost	Important factors	Reference
4. Reactive wall 5. Biologically active wall			
1. Pump and air stripping	2	Energy consumption	(Bender et al. 1998)
2. 1 with added activated carbon and in situ bioremediation with nitrate		Production of electron acceptor	
3. 2 with hydrogen peroxide instead of nitrate			
1. Pump and vacuum steam stripping	2	Energy consumption	(Vignes 1999)
2. Pump and active carbon cleaning			
3. No action			
1. Funnel and gate (steel wall)	2, 3	Steel amount	(Bayer and Finkel 2006)
2. Funnel and gate (bentonite/cement wall)		Active carbon	
3. Pump and treat		Pump energy	
1. Pump and treat	2	Pavement treatment area	(Cadotte et al. 2007)
2. Bioslurping, bioventing and biosparging			
3. Bioslurping, bioventing and chemical oxidation			
4. Ex situ biopiles			
1.Pump and adsorption	See Sect. 2.1.3	Energy use	(Andersson 2003)
2. In situ bioremediation		Groundwater use	
1. On site biopiles	2	Site preparation and closure (site landfilling)	(Toffoletto et al. 2005)
2. Ex situ biopiles		Soil toxicity	

long timeframes that complicate the environmental evaluation. Many of the studies in Table 2.1 have been performed on sites where site development was imminent, which also excluded long-term remediation options.

2.2.1 Doing Nothing

Not acting is not necessarily best from a holistic environmental perspective. If the contamination remains in the soil, there is an impact on local human health and on the biosphere. The alternative of ‘no action’ was included in three cases in Table 2.1:

Diamond et al. (1999) and both cases described in Vignes (1999). In all these comparisons there were alternatives preferable to doing nothing, based on the environmental evaluation from a broader perspective than a local risk assessment. In other words: the environmental cost of the most benevolent treatment outweighed the cost of leaving the pollution in the soil. However, in none of the studies was 'no action' the worst alternative: when the entire environmental effect is taken into account, treating the contaminated soil can result in a net environmental cost, i.e., making things worse.

2.2.2 *In situ Bioremediation Can be Good or Bad*

In situ bioremediation can be both the best and the worst alternative for the environment. There is no need for excavation, transport and landfilling with in situ treatment, and consequently the environmental cost of these primary impact activities is avoided (see Sects. 2.2.4 and 2.2.5). On the other hand, there is an environmental cost through secondary impacts, such as producing wall materials, electron acceptors or other additives. These secondary impacts can add up to a considerable environmental cost. They are often excluded from traditional LCA since they are difficult to quantify within the LCA framework, but they are included in most studies dealing with soil remediation.

Another important aspect for bioremediation is the common need to pump down additives or air, or to pump up groundwater. Pumping uses energy, with concomitant consequences (see Sect. 2.4.1.1). The energy use can add up to a considerable impact when treatment times are long, as they often are for bioremediation.

The influence of energy use is illustrated in Sect. 2.3, where energy used for bioremediation or pump and treat remediation is a determining factor for choosing the best treatment option. The influence of chemical production is shown by Bender et al. (1998). The latter compared long-term groundwater extraction versus a combination of groundwater extraction and in situ bioremediation. Bioremediation was achieved by adding nutrients and an electron acceptor to the water before pumping it back into the soil. Bioremediation had the lowest impact on the environment when the electron acceptor was nitrate, but the impact was highest when the electron acceptor was hydrogen peroxide. Hydrogen peroxide use resulted in the highest energy demand, the highest waste production, and was disadvantageous from most other perspectives. Long-term groundwater extraction, without increased bioremediation, had an intermediate impact on the environment. In this case, pumping energy was a minor consideration.

2.2.3 *Other In Situ Methods: Manufacture of Materials*

The secondary impact can also be dominant for other in situ methods, such as funnel and gate systems, permeable reactive walls, or isolation through covering the site with low permeability materials (see also Sect. 2.4.1). The production of wall and cover materials is an important source of environmental cost. Special attention should be paid to the use of iron and steel. Production of steel causes considerable secondary impact through the use of energy.

This is illustrated by ScanRail Consult (2000a) where two permeable reactive barriers for the treatment of chlorinated hydrocarbons on one site were compared. The barrier was either a continuous wall of iron filings (chemical degradation), or a series of wells where air mixed with methane was injected to increase biodegradation. The biodegradation barrier was the environmentally most beneficial, due to the environmental cost of steel production. The iron filings were made from scrap metal; otherwise the environmental cost would have been even higher (ScanRail Consult 2000a).

Another example is the use of steel or cement/bentonite for a funnel and gate system. In this case, a funnel of steel was created at the site of a former gas plant, to guide contaminated groundwater to the treatment at the gate. Environmental evaluation showed that the main environmental impact was due to steel production. When the steel walls were (hypothetically) replaced with cement/bentonite mixtures, environmental impact decreased to a level comparable with pump and treat (Bayer and Finkel 2006).

2.2.4 Excavation or Immobilisation: Surfaces and Transport

Ex situ treatments are generally intermediate alternatives from an environmental perspective. The impacts are even more site-dependent than for in situ techniques. In particular, the distance that the soil is transported to the treatment facility or landfill plays a major role. Generally a distance of 100–200 km is the limit at which other alternatives become extremely attractive. When an ex situ treatment is selected for a site, it is advantageous to minimise transport and choose an environmentally friendly transport option.

The importance of secondary processes (manufacture of materials, etc) is also prominent in the case of ex situ treatment and immobilisation. One of the major causes of environmental impact is the construction of a working surface for remediation. In particular, for on site remediation when the surface is only used once, the manufacture of the surface is important. The wear and tear on the surface in a permanent plant is also a cause of environmental impact through energy and material use for construction (Cadotte et al. 2007). The same applies to a low-permeability surface, constructed to decrease leaching from the soil and human exposure to the soil contaminants.

2.2.5 Landfilling

The disadvantages of surface construction and transport also apply to landfilling as a remediation option. But a third negative aspect of landfilling is the impact on biodiversity. This is seldom included in evaluations, but when it is included the impact is considerable. The use of land for contaminated soil landfill entails that the land will not be available for other purposes or functions. Biodiversity is particularly threatened by lack of available land. If filling materials for the treated site are taken from another area, usually this area also suffers from a decrease in biodiversity. The comparative merit of landfilling as an option strongly depends on the value placed on surface use.

2.3 Case Study: Two Simple Models for a Petrol Filling Station

To further explain the concepts discussed above, we include the results from a case study. The case study had two aims: to compare two easy tools for holistic environmental assessment and to gain insight in the environmental cost from two treatment options. This was done by comparing two treatment techniques in two computer models, using approximately the same data set (Andersson 2003).

The treatment techniques that were compared were pump and treat with absorption (below called adsorption for short), and bioremediation. The computer models used are named REC and UvA, and have been developed for evaluation of environmental impacts caused by treatment of contaminated sites. Both models are based upon life cycle assessment thinking.

2.3.1 Site Description and Treatment Techniques

The data used is from the petrol filling station at Blackstad (Sweden) that was discontinued in 1980. A residential building and a car repair shop stand on the 2,000 m^2 estate. The soil was slightly contaminated with PAH (polycyclic aromatic hydrocarbons), benzene and aliphatics. The groundwater needed treatment, since it was used for irrigation and was contaminated with aliphatics, BTEX (benzene, toluene, ethyl benzene, xylene) and PAH.

Two alternatives were tested in a comparison of the environmental impact models. In one alternative the groundwater was pumped up, filtered, and released to a nearby ditch (the adsorption technique). The other alternative (the bioremediation technique) was enhanced biological degradation by adding bacteria, nutrients, and electron acceptors (air for a longer period, hydrogen peroxide for a short period) to the water and re-infiltrating. The techniques were simplified for the models, and cleanup times and results were assumed to be similar. This corresponds to evaluating the expected environmental performance prior to choosing a remediation technique.

2.3.2 The Case Models

The REC and UvA computer models were used to evaluate the environmental impact (Volkwein et al. 1999; Drunen et al. 2000). These are easy-to-use, West-European models. Unfortunately, no corresponding Swedish model was available. Complicated models would be preferable for an in-depth analysis of the environmental aspects of various treatments, but for everyday decisions simpler models are more suitable.

The REC model was used to assess environmental merit. The modules for Risk reduction and for (financial) Cost were not tested here. The UvA model (Umweltbilanz von Altlastensanierungsverfahren) has a more detailed LCA approach than the REC model, but does not include risk or financial assessment (Volkwein et al. 1999).

Realistic estimates of use of equipment and energy were available from the practical application of both techniques on the site. Detailed data is shown in Table 2.2 (REC) and Table 2.3 (UvA). This will also give you some idea of the data required to run the models. Input data is relatively simple since the models include average values for many processes, such as energy use and emissions from secondary processes like the production of machinery, pipes and hydrogen peroxide.

2.3.3 The Case Results

The REC and UvA models differed with respect to which treatment was the most advantageous. The REC model showed that the adsorption technique caused higher

Table 2.2 Data input for the REC model

Data category	Adsorption	Bioremediation
Current situation		
Quality objective (μg l^{-1})	100	100
Intervention value (μg l^{-1})[a]	100	100
Concentration of aliphates (μg l^{-1})	200	200
Volume of contaminated groundwater (m^3)	200	200
Treatment category		
Load (m^3a)	0.00001	0.00001
Consumed groundwater (m^3)	200	50
Volume of groundwater to pump (m^3)	200	50
Lifting height (m)	6	6
Volume groundwater to treat (m^3)	200	200
Waste (m^3)	0.0018	0
Land use (m^2)	5	5
Time requirement for remediation (a)	0.5	0.5

[a]Value to evaluate the risks of contaminated sites (Swedish guideline value)

Table 2.3 Data input for the UvA model

Data category	Adsorption	Bioremediation
Risk (before remediation/after remediation)[a]		
Relevant risk (Maßgebliches Risiko)[b]	5.3/4	5.3/4
Unsecured area	10.3/4	10.3/4
Area of the site (m^2)	2,000/0	2,000/0
Volume of contaminated groundwater (m^3)	200/0	200/0
The site is used as:	Residential area	Residential area
Demands		
Workdays to build the equipment (days)	3	3
Time requirement for the remediation (days)	180	180
Average density of the soil ($t\ m^{-3}$)	1.8	1.8
Distance to settlement (m)	100	100
Land use (m^2)	5	5
Volume of soil to treat (m^3)	1	1
Volume of groundwater to treat (m^3)	200	200
Hydraulic pump		
Running time (days)	180	180
Pump rate (m^3/h)	0.05	0.01
Lifting height (m)	6	6
Reinfiltration (%)	0	100
Adsorption		
Total mass of hazardous substances (kg)	0.04	-
Concentration capacity of activated carbon (%)	5	-
The activated carbon after use is:	Disposed	-
Bioremediation		
Running time (days)	–	180
Sodium nitrate ($NaNO_3$) (kg)	–	0.5
Hydrogen peroxide (H_2O_2) (kg)	–	0.1

[a] Changes had negligible effect on the outcome of the model
[b] Acceptable risk level

environmental impact than the bioremediation. The categories in which the absorption technique caused more environmental costs were consumed groundwater, energy, air emissions and waste.

The category which had the most significant environmental costs, for both techniques, was land use. The land use in the case study was the area occupied by the equipment for the pump and treatment process (5 m^2). The reason that land use resulted in greatest environmental cost, even though 5 m^2 is not a big area, is that the techniques had a low impact generally, a consequence of the low contamination of the site.

The main reason for the higher environmental costs for the absorption technique in the REC model was that groundwater was released to a ditch after the adsorption treatment. In the bioremediation alternative the water was infiltrated back, and therefore no groundwater was consumed. Besides groundwater use, the adsorption treatment also consumed more energy. This was due to the fact that the total volume of contaminated groundwater was pumped up before treatment was complete, while in the case of bioremediation only part of the groundwater was pumped up. Energy use leads to increased air emissions and waste as well, and the discarded filter material from the adsorption treatment also produced waste.

The UvA model showed on the contrary that bioremediation was inferior to adsorption, due to a much higher energy use. Detailed analysis showed that in the bioremediation treatment module, nitrate and hydrogen peroxide were added using a metering pump, and that the difference in energy use was due to the continuous functioning of this pump. The metering pump impact dominated any other differences, but groundwater loss was clearly visible as an important cost in the UvA model as well as in the REC model.

Activated carbon filter material and bioremediation additives were negligible in comparison with pump energy use and groundwater in the UvA model. This is contrary to the results from Bender et al. (1998), who found that production of additives was predominant in his similar comparison using the UvA model, though groundwater use also constituted a largely disadvantageous factor in their study.

The estimated energy use was four times lower in UvA then in REC for identical actions. The difference was probably caused by the different data sets, i.e., the activities and environmental impact parameters, as well as their values, that are included in the models.

2.3.4 Conclusions from the Case Study

The compared treatments had a low environmental cost generally. This was due to the low level of contamination of the site, and the low intensity of the remediation techniques that were used. The most significant difference between the techniques was due to energy use, but the models disagreed as to which technique was the most environmentally friendly.

The loss of groundwater was a notable factor in both models. This was not a surprise, since groundwater is a scarce resource in both Germany and the Netherlands. However, this is not the case in this Swedish region. The groundwater quality needed to be improved (through remediation), but the loss of 200 m^3 groundwater hardly constituted an important impact on the environment.

In summary, the models were helpful in identifying the important environmental effects from the treatment alternatives. Energy use, land use, and groundwater loss were important impacts, while additives and filter materials were not. The detailed results were influenced by the system boundaries, and the energy calculations in particular need to be adapted to the actual situation for a fair comparison of the treatment options.

In reality, the two treatments (adsorption and bioremediation) were used consecutively, starting with the adsorption technique. The contaminant concentrations did not decrease sufficiently using adsorption, and afterwards the bioremediation technique was initiated with successful results. The concentrations in the groundwater have now decreased to acceptable levels, and remediation activity has ceased.

The lower cleanup level resulting from the adsorption technique was ignored for the model and technique comparison, since it was not expected beforehand. Naturally, ineffective treatments should be avoided. Their environmental cost is not offset by a benefit, and thus they are only disadvantageous to the environment.

2.4 Improving Specific Remediations

Thus far we have discussed treatments in a general way (Sect. 2.2) and given a more detailed example of a comparison of treatment options (Sect. 2.3). Now we would like to provide direction for improving site-specific treatments. This need not be complicated or time-consuming. Sometimes a simpler checklist can be as relevant as a model. We include a checklist that can be a starting point when considering a treatment technique.

It is important to think through the entire chain of events and materials in order to do a holistic environmental impact assessment. Much improvement may be achieved simply through knowledge of the environmental effects, and awareness that remedial actions have an environmental impact. Therefore we describe the most significant environmental impacts below.

2.4.1 What to Consider

2.4.1.1 Energy

The use and source of energy is one of the environmental impacts of major importance in life cycle assessment. The source of the energy was also important in the case study. In this case it was possible to drive the pump through the Swedish electricity net (water power, nuclear power, and some fossil fuels). A solar cell may have been worth considering, and a fossil fuel aggregate as a power source may have increased the environmental cost considerably.

Energy use occurs in many activities and steps in soil treatment. Fossil fuel is commonly used as the energy source:

- It is the major source for the transport of soil, people and equipment to and from the site.
- The energy needed to drive pumps for in situ remediation is another common energy-demanding activity.
- The energy used to manufacture steel and hydrogen peroxide is a third activity where the energy demand is high and mostly based on fossil fuel.

2.4.1.2 Scarce Natural Resources

Evident scarce resources are soil and backfill, groundwater, fossil fuels and metals. The materials and additives discussed in Sect. 2.2 reoccur here. The manufacture of the materials uses energy and scarce natural resources. This is an important factor, but for a really fair valuation it may need the application of LCA-like methods. It is difficult to assess the impact caused by manufacturing. For some products the reviews may have been done, or environmental assessments may have been done on some of the products which can be used as a basis. It would also be useful to have national and European guidelines, or guides summarising the environmental impacts available as a basis for simple but holistic environmental assessments, but for most products such information is unfortunately not yet available. Despite the lack of quantitative and supporting information, a qualitative discussion may be relevant regarding potential environmental impacts using different materials.

2.4.1.3 Land Use

Land surface is also a scarce resource, but its special nature has put it into a category by itself. Loss of ground surface is a major problem for maintaining biodiversity. Soil remediation may cause surface loss in various places: consider specifically the contaminated site itself, the area used for treatment or landfilling, and the area depleted by the production of backfill.

2.4.1.4 Emissions

Most forms of energy use cause emissions to air, and the result may be global warming, acidification, particle generation, photo-oxidant formation, eutrophication or human toxicity. Global warming is caused by carbon dioxide (CO_2) and other greenhouse gases, acidification is caused by emissions of sulphur oxides (SOx) and nitrogen oxides (NOx), photo-oxidants are caused by emissions of organic compounds (CO, VOC) and (NOx), eutrophication is caused by nitrate and phosphate emissions, and particulates are formed from non-efficient combustion in addition to dusting. The total and type of emissions depend on the emission source and the combustion efficiency.

Minimising the activities and steps using energy, and the energy need in each of the activities and steps involved, therefore is often the major step needed also to reduce many of the impacts on a regional to global scale which in general are due to air emissions. Most often, this is also profitable both from an economical and a general environmental perspective.

Emissions to soil and water may arise from the contaminants at the actual site and from additives used in the remediation process. Emissions from contaminated soil to the ground or water can also occur from the contaminated soil at a landfill or at a site for ex situ remediation. The extent of emissions release depends on the specific conditions. The more closed the system, the less uncontrolled the emissions. In controlled systems the contaminants are either trapped, destroyed or concentrated in processes, where on the other hand other environmentally cost-demanding steps, such as energy use, are involved.

The emissions to air, soil and water can also occur in different steps and activities involved in the production of additives or other products used in the remediation. As in the case of scarce materials, for some products environmental assessments may have been done that can be used, but for most products such information is unfortunately not yet available.

2.4.1.5 Human Exposure

Human toxicity may be due on the one hand to intake from the contaminated site, such as contaminated drinking water, but also due to emissions from the site, combustion and dust exposure caused by the remediation activities. The emissions from the site during remediation can be emissions of toxic gases released or the soil contaminants becoming more mobile and open for exposure during the remediation. Dusting increases while remediating, and contaminants may be carried by the dust. Treatment actions also cause increased noise and nuisance. Those should of course be included in an environmental risk assessment of remediation alternatives.

2.4.2 Tools to Use

Even simple efforts may lessen the environmental cost, despite the lack of information that would ensure a very fair environmental impact assessment. Simply by reading this chapter you may already have changed your next remediation. Taking a few hours to consider environmental impact can improve the result (but more time would be better). There are tools available to help with this, ranging from simple models to complete life cycle assessment.

If there is an opportunity to make a quantitative evaluation of remediation options, models should be chosen that were constructed for use in situations that resemble as closely as possible the current planned remediation. The source of the energy use is important, as is the value placed on land surface and groundwater resources. It should be checked that the models include these factors, since many traditional LCA models focus heavily on energy use. Other environmental costs may come unusually high in soil remediation, and need to be considered (Suer et al. 2004). Generally, local models are preferable, and the in data needs should correspond to the available in data to avoid excessive guessing. The reference list includes several options.

Otherwise a qualitative evaluation may be suitable. A structured qualitative approach is life cycle management (LCM) in four steps described by Diamond et al (1999). In the first step, goal and audience for the LCM are identified, and the processes are described for the entire remediation (including for example secondary materials, contaminant concentrations, and activities to close the site). In the second step, the processes are associated with potential impacts, for example energy use and waste production. Noise and other nuisance can also be included.

All these impacts are ranked as low, moderate or high. The impacts are evaluated in the third step to decide on actions to lessen the environmental impact, and applied in the fourth step.

2.5 Getting started, what to consider:

Energy

Transport
Pumping
Manufacture of additives
Manufacture of materials

Scarce natural resources

Soil and backfill
Groundwater
Fossil fuels
Metals

Land use

Landfill, temporary storage, working area
The time perspective is important

Emissions

To water (contaminants, chemicals, additives)
To air (mainly due to transport and energy use, dust)

Human exposure

Contaminated site
Working environment during remediation
Transport emissions
Noise and nuisance

2.6 Conclusion

There is great room for improvement in everyday remediation, since the holistic environmental aspects are often ignored completely today. Even a limited review of the environmental impact can indicate which techniques to avoid, and where there is potential for improvement. Such a review should consider the entire chain of the remediation. The list in Sect. 2.4.2 may be helpful in making it.

Research continues on environmental impacts, using more complete and complicated methods than what is possible in everyday remediation. The results of these detailed studies will help to further determine the major areas where improvement is desirable/a priority. Use of energy, secondary materials (especially surfaces and electron acceptors), and land use have been identified so far as major impact parameters in a holistic environmental assessment of contaminated land.

Soil remediation measures may have an overall negative impact worse than doing nothing and leaving the contaminants in the soil. But usually there is a more beneficial alternative available. Experience and a good knowledge base are required to identify and exploit those possibilities. It is recommended when doing the first holistic environmental assessment to involve, or rely on someone experienced in life cycle assessments to ensure the robustness of the evaluation.

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