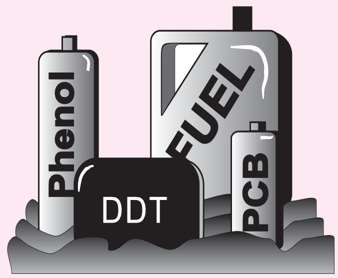
SOIL PROTECTION AND SOLID WASTE MANAGEMENT

18

Touching and managing soil is a basic human experience most often expressed as we care for plants in the windowsill, in the garden, or - nowadays for only few of us – in agriculture. In the Baltic Sea region soil is often not a threatened resource and is taken for granted. The photo is of a field prepared for planting potatoes at a small farm in southern Sweden. (Photo: Lars Rydén.)

"There is no life without soil and no soil without life… Globally the total pool of organic carbon in soils is three times higher that the total organic carbon in the above-ground biomass… It is twice as high as the total organic carbon in the atmosphere… Many solid, liquid or gaseous inorganic or organic compounds deposit on the soil... There microbiological and biochemical processes leads to mineralization and metabolization of organic compounds… These biological reactions become increasingly important as they contribute to global change through the emission of gases from the soil into the atmosphere." (Blum, 1999)



Soil is the third environmental resource on which we critically depend, in addition to water and air. Soil is an extremely thin and sensitive "skin" on the planet. Life has developed on this skin-like layer, often only meters thick.

Soil as a resource has always been there in huge quantities and it is not until recently that it is clear that soil is a resource that we need to take care of, protect and restore. Worldwide soil is becoming a very urgent problem and destruction of soil is perhaps the largest threat against the longterm productivity of the planet. Loss of soil is due to erosion, either through water or wind. Agricultural soil is impoverished through loss of organic content, the humus, by mineralization, and loss of nutrients by drainage. This is a concern in some parts of the Baltic Sea region and important worldwide. In the Baltic Sea region some forest soils are harmed by acidification as well.

Soil in industrial and urban areas is threatened by contamination and pollution. The reason is more than anything lack of an acceptable management of solid waste. The customary way to get rid of solid waste was, and too often still is, just to empty it in the nearest non-occupied area, such as a landfill or deposit. Much waste, especially industrial waste, leaks toxic substances and thus is a threat towards soil, water, and sometimes air.

Contaminated industrial sites are called "brownfields." In brownfields the soil may contain tar, fuels, oil or other hydrocarbons, not least phenols, resorcinol or collectively creosote. It may also contain chlorinated hydrocarbons, e.g. PCBs, or chloro-phenols, to mention a few of the more common contaminants. Thirdly, large amounts of heavy metals are present in some sites.

Polluted land areas constitute a risk since they may leak to ground water and pollute large parts of the environment. There are examples of old landfills, and old industries that threaten entire drainage areas. To protect human health and the environment there are thus good reasons to restore such sites. In cities, old industrial sites are also valuable e.g. as new residential areas or areas for new activities. Thus, economic development is also a reason for restoration. However, remediation of destroyed soil is difficult and costly. Technologies for soil remediation include physical, chemical, and biological methods. Today large national programs for the restoration of brownfield sites exist in many countries. In the Baltic Sea region in addition to the industrial sites there are also hundreds of former Soviet military bases that are polluted.

The waste management approach today is to avoid deposition of a material as long as possible. Waste is seen as a resource with an economic value that is to be used. Recycling and reuse strategies are thus developing.

Waste management is often a task for engineers even if much of the technologies developed for purification of water, air, and soil are based on processes in nature. In old societies very little was wasted. Now we have to return to this approach. Waste is a resource to be recycled.

Authors of this chapter

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Soil protection and solid waste management

Soil management

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Soil management

Soil as a resource

The Earth's crust, forming the outermost layer of the planet, represents less than 1% of its total mass and 0.5% of its radius. This corresponds to a depth of some 35 km on the continents, which in turn make up 30% of the total surface (Chapter 2). The rock, which is only a thin layer covering the surface of the crust, is continually worn down in a process called weathering, due to biological, chemical, and physical processes. In this way the *soil* is produced, an extremely thin and sensitive "skin" on the planet.

Life has developed on this skin-like layer, often only meters thick. Soil is of central concern for environmental quality. Miklaszewski (1907) wrote concisely, "there is no life without soil and no soil without life."

The vast majority of soils are a mixture of four components: inorganic matter, organic matter, soil water (groundwater), and soil atmosphere. Different soil types have very different amounts of these four components. Soil organic matter is a mixture of partially degraded plant and animal material and matter produced by microorganisms. The fertile organic soils with a high content of organic matter are not the norm. Most soils have less than 10% organic matter, they are so-called mineral soils.

Soil science is the discipline in which soil and its properties is studied. These include increased sustainable productivity in agriculture; land use planning; managing of water resources; avoiding or treating degradation and pollution of soils and water; conservation of biological diversity; and limitation of the greenhouse effect through carbon sequestration (Petit, 1998; Debicki and Sklodowski, 1999). The point of departure is that soil is a non-renewable resource. This is a practical truth. Weathering does create new soil but in a time frame that is much slower than most human-caused erosion processes. Blum (1999) stresses that soil is an absolutely limited resource which cannot be extended, enlarged, or substituted.

Figure 18.1. In some parts of the Baltic Sea region the soil is among the richest in the world and is an invaluable resource. In southern Sweden and in Denmark the production in these soils approach 10,000 kg of crop per ha. (Photo: Lars Rydén.)

Soil functions

A holistic approach to the role of soil in a sustainable environment was presented by Blum (1999). He indicates several different soil functions. Here we will enumerate three ecological and three economic/technical functions. First the ecological functions:

- *Productivity*. Soil is a base for the production of food, fodder and wood for pharmaceutics, textiles, renewable energy, etc. The productivity of good soil provides 100-200 kg ha^{-1} day^{-1} of biomass in central and northern Europe (Kowalik, 1994). All terrestrial ecosystems are dependent upon the photosynthetic productivity of the vegetation.
- *Filtering*. Soil filters water containing pollutants and binds several of these. Soil properties strongly influences the water flux between the atmosphere and groundwater as well as the gas exchange between terrestrial and atmospheric systems, including the carbon dioxide balance and global warming mitigation. This is critical for the quality of drinking water and control of uptake of elements from soil by plants, which influences the quality of food.
- *Habitat for microorganisms*. Soil is a biological habitat and gene reserve, with a large variety of soil organisms with more species in number and quantity than all other above-ground biota together. Therefore soils are a main basis of biodiversity. Genes from soil become increasingly important for many technological, especially biotechnological and bioengineering processes. One of the examples is production of streptomycin from soil

Figure 18.2. In some areas of the Baltic Sea region the organic component in soil is small and the soil is brown or light, and dominated by sand. Here in northern Poland, an suitable use of the soil is cultivation of potatoes. (Photo: Lars Rydén.)

Case

Box 18.1

Legal regulation of soil protection in Poland

Classification of soils

The base of soil protection in Poland is the legal regulation of soil quality. In 1956 the Polish Parliament decided that soils should be divided into six classes, so-called "bonitation classes". This classification was needed for taxation of farmers and for planning proper land use. The six classes introduced were from the best (class I) to the worst soils (class VI) (Dz.U. 1958/5/21).

One classification was established for ploughed soils, and others for forest soils (six classes) and meadow soils (six classes). The worst class of ploughed soil (VI) is considered to be dedicated for aforestation or to be used as a base for industry, housing, roads or as a source of minerals. According to the decisions of the Parliament, all of Poland is to be covered by soil classification maps in the scale of 1:25,000 or better.

Obligations regarding soil

The Polish Environmental Protection Act (Dz.U. 1994/49/196), introduced in 1990, enumerates the soil protection obligations. The Act prohibits:

- pollution or destruction of the soil surface and the local landscape;
- destruction of local vegetation;
- drainage or irrigation of soil if it is not needed,
- decreasing the organic matter content of the soil,
- decreasing the fertility of soil,
- introduction of chemicals into the soil by direct or indirect actions, and
- prevention of the ecological equilibrium of the soil ecosystem.

The main activity should be devoted to the protection of high soil productivity, stabilisation of ecological equilibrium, and prevention of damaging land uses. The most important and dangerous human influences are: too high a level of mineral content or organic fertilisation, as it may destroy the natural equilibrium of the soil processes and generate leaching of pollutants from soil, that can damage water, vegetation, ecosystems and wildlife. A too intensive application of pesticides is still not regulated in Poland.

Degrees of soil damage

Likewise the new Polish Act on Soil Protection (Dz.U. 1995/16/78) indicates some new obligations. Three degrees of soil damage are introduced:

1. degradation – lower crop yields, lower forest growth;
2. devastation – soil looses its ecological functions and vegetation cover;
3. substitution – of the ecological functions by industrial or urban functions. If the soil is taken over by industry, housing, roads, solid waste dumps and is loosing the agricultural or forest use, it is necessary to pay for this damage.

Fees – the Soil Fund and the Forest Fund

An environmental fee has been introduced, paid for every hectare of the soil, taken from agriculture or forestry. The fee is calculated in tonnes of grain per hectare and year or in cubic meters of coniferous timber per hectare and year. The price of grain or timber is established every year according to the state statistics. For agricultural soils lost for production the environmental fees are collected by a special Soil Fund (part of the Environmental Fund). For forest soils lost for timber production the fees are collected by the special Forest Fund.

Money collected by the Soil and Forest Funds are used for recultivation of devastated soils or for control of the quality of food produced on the degraded soils. Research on soil protection may be supported from these two Funds. If the soil is negatively influenced by an industry, the duty of the polluter is to pay for monitoring of soil degradation, and establishment of a new land use, with a new equilibrium between soil and vegetation. The regulations have been implemented very recently and it is still difficult to evaluate the efficiency of this Act on Soil Protection.

National soil regulations differ but in many countries there are similarities to the Polish regulations.

Piotr Kowalik

bacteria, discovered by Selman Waksman in 1944, and more recently many other pharmaceutics like production of chloramphenicol, tetracyclin or cyclohexamidin by soil microorganisms.

In addition to these three *ecological* functions of soils, it has other functions linked to technical, industrial, and social uses.

- *Infrastructure*. Soil is a spatial base for different structures, like industrial premises, housing, transport, sport, recreation, dumping of refuse, etc. This gives rise to considerable and irreversible soil losses, counted in Austria to be about 20 ha of soil per day and in Germany about 120 ha per day. A recent high soil consuming activity in many countries is the construction of highways.
- *Natural resource*. Soil is a source of raw materials, e.g. clay, loam, sand, gravel, rocks, and minerals in general. Recently soil has became an important source of water and is becoming more often used as a reservoir and source of heat or cold.
- *Landscape*. Soil is related to the formation of the landscape, in which we live. It is an important part of our cultural surrounding. Soils are important

Soil functions

- productivity
- filtering
- habitat for micro-organisms
- infrastructure
- natural resource
- landscape

as a geological and cultural heritage, protecting many archaeological treasures of high value for understanding human history and development.

Sustainable use of soils is possible only if the six functions are harmonized by local and national authorities, creating a policy of sustainable land use.

Soil protection

The soil environment is a gift of nature and should be protected just like natural forests or natural wetlands. At the same time the soil is seen by the farmer as a productive environment, and managed by mechanical, chemical, biological and other means. Erosion, degradation, devastation or change of land use are the most important processes to be understood in the context of soil protection.

Legally, protection of soil *quantity* is regulated by the acts dealing with regional planning and protection of the landscape, forest, pastures, farmlands or wetlands. Protection of soil *quality* is needed to protect drinking water and the quality of the food produced in the soil.

The use of soil may lead to degradation of soil quantity and quality. The visible conflicts between the six functions of soil described above should be well understood. The most important conflict is between *ecological functions and industrial uses of soil* that result in irreversible soil losses. Another is the *use of soil for dumping of pollutants* (see below). Soil contamination is a cause of forest decline, degradation and devastation of agricultural areas, and increasing soil erosion. A high level of heavy metals in soil, pesticides, manure, sewage sludge, sulphur and nitrites from acid rain may reduce crop yield and soil productivity.

Soils have a capacity of self-purification by mechanical filtration, chemical buffering and biochemical transformations when waste is deposited or precipitated on the soil surface. However, this capacity is not always enough. It may contaminate soil water and vegetation in the human food chain. Therefore pollution of soil should be avoided as long as possible.

Legal regulations of soil quality

Soil quality is regulated by legal instruments. Some European Union directives apply, but only in very limited areas, for example for the problem of agricultural utilisation of sewage sludge (Directive UE 86/278/EEC). The Netherlands and Germany are proposing their own regulations (Duch List or Berlin List). Poland (see also the Case Box) decided to compile all existing regulations and to publish the preliminary regulations as prepared by the Polish State Inspectorate on Environmental Protection (PIOS) in 1995. Because of the lack of a legal framework for protection of soil quality, the preliminary proposals were published for experts on environmental impact assessment and for the environmental authorities on the local, regional and state levels.

Polish regulations introduced three different areas: A, B, and C (see Table). “A” areas refer to natural reserves and areas where groundwater is used for drinking water supply. “B” areas refer to agricultural fields (production of grain, pastures, orchards, etc.), forestry, recreation areas, and soil surrounding households. “C” areas are mainly industrial and municipal centres. In “A” areas it is necessary to protect the whole depth of the soil profile, in “B” areas soil protection is limited to the depth between 0 and 30 cm.

Table 18.1. Soil classes. Requirement of soils of different classes in Poland. Some examples (mg / kilo soil)

Category of pollutant	max area A	max area B
Cr Chromium	< 20	
Cu Copper	< 36	
Zn Zinc	< 140	
As Arsenium	< 20	
Mo Molibden	< 10	
Cd Cadmium	< 0,8	
Hg Mercury	0.3	
Pb Lead	< 85	
CN	< 1	
Benzen	< 0.05	< 0.1
Toluen	< 0.05	< 0,1
Xylen	< 0.05	< 0.1
Fenol	< 0.05	< 0.1
Sum aromatic hydroc.	< 0.1	
Sum of APH	< 1	
Sum of chlorfenols	< 0.1	
Cyclohexan	< 0.1	
Sum of WWA oxidants	< 1	
Mineral oil	< 30	< 50
Sum of petrols	< 20	

The importance of soil

The function of soil “...becomes increasingly important, because of the many solid, liquid or gaseous, inorganic or organic depositions, on which soils react through mechanical filtration, physical or chemical absorption and precipitation on its inner surfaces, or microbiological and biochemical mineralisation and metabolization of organic compounds. These biological reactions may also contribute to global change through the emission of gases from the soil into the atmosphere, because globally the total pool of organic carbon in soils is three times higher that the total organic carbon in the above-ground biomass and twice as high as the total organic carbon in the atmosphere” (Blum, 1999).

Figure 18.3. Erosion. Erosion of soil is in general not serious in the Baltic Sea region. Still some one mm of soil is lost through erosion yearly and is transported by water. This corresponds to 5.7 kg per person and day in the southern Baltic Sea region, according to German data (Bringezu et al., 1995). Only part of this makes its way to the sea. Monitored sediment transport by rivers into the Baltic Sea adds up to about 7.5 million tonnes yearly or about 100 kg per person and year. (Source: Magnuszewski, 2000.) (Photo: Pawel Migula.)

Threats to soil quantity and quality

Loss of soil – soil erosion

On a world scale erosion of soil by wind and water may be the single largest threat against future productivity of the Earth. Soil loss is mainly related to deforestation of large areas in the South exposing a thin layer of fertile soil to heavy rains and winds, to overgrazing of grasslands by too large cattle and goat herds, and over-tilling of the soil by inappropriate cultivation methods. Also in the West erosion due to modern agricultural methods is extensive. With the present methods of mechanical agriculture e.g. the state of Texas in the USA may become a desert in one or two generations.

In the Baltic Sea region soil loss are high but not alarming due to the good soils in the area. Mechanical agriculture leads to treatment of a very extensive amount of soil. Figures available for Germany (Bringezu et al., 1995) tells us that 0.3 ha per person is ploughed every year to a depth of 0.2 m. This annual movement of solid material corresponds to about 600 m^3 or 1,200 tonnes per capita. The loss of soil due to erosion is, however, estimated to be not more than 1,800 kg per year and person. This equals 5.7 kg per capita and day or a total of 16 megatonnes per year in Germany or to about one mm of soil surface. Other reasons for soil loss include grazing: a cow ingests some 2 kg of soil per day when grazing. Much of the eroded soil ends up in rivers where it is transported as sediment to the Baltic Sea. River transport adds up to a total amount of 7.5 megatonnes per year, or about 100 kg per person and year in the drainage basin (Magnuszewski, 2000).

Figures for soil renewal through weathering would be interesting but are lacking at present.

Loss of organic material – soil impoverishment and desertification

As soil is cultivated nutrients are taken up by the crop or vegetation. Harvesting thus corresponds to nutrient loss which needs to be replaced by fertilization if the soil is not to become poor. Repeated burning, cultivation and removal of harvest in historic times made the soil health very poor in vast areas in the region (see Chapter 7).

Agriculture may turn black soil, rich in humus i.e. organic material, into poor soil. Tilling of soil increases the microbiological processes in the soil and degrades organic matter with the release of carbon dioxide to the air while nutrients, nitrate and phosphate, stay in the ground but risk being lost through run off after mineralization. The organic material needs to be replaced by e.g. straw to keep up the humus content. This process of loss of black soil is relevant in the Baltic Sea region, e.g. in Poland.

In the extreme, the loss of organic substances leads to desert formation, also called desertification. This is not a serious problem in the Baltic Sea region but is serious in the developing world (see Outlook Box).

Acidification and salination

Acid rain has turned large areas with low buffering capacity to acid soils. These soils have typically been forest soils.

The consequences of acidification of soils are described in Chapter 11. In general it leads to lower productivity and reduced bio-diversity of these soils. Acidification of soils are most typical for areas with poor soils in western Sweden and Norway.

Threats to soil

- erosion, loss of soil
- desertification, loss of organic material
- acidification, reduction of pH
- salination, increased salt content
- overmoisture, too much water
- contamination, pollution by chemicals

Increased salt content in soil is called salination. Salination may be the result of extensive irrigation. If the water used for irrigation contains mineral salts, the salts stay in the soil and concentrations build up. At some point the fertility of the soil is harmed, and in the end it turns into desert.

Salination is in general not a problem in the Baltic Sea region. A contemporary serious case of salination is the Aral Sea area in Siberia, where many years of extensive irrigation of cotton fields had disastrous results both at the Aral Sea itself and along the rivers draining into the sea.

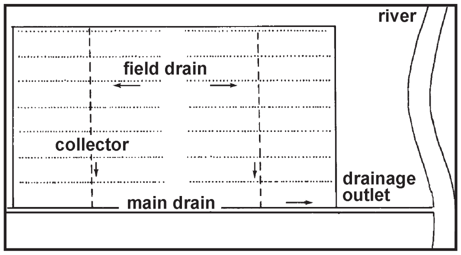


Figure 18.4. Drainage. Most fields in modern agriculture are drained through subsoil drainage systems. The older practice was to dig ditches, which were a considerable hindrance in agriculture. (Linnér, 2000.)

Too much or too little water – drainage of wet soils

Using water content as a parameter soils may be divided into five categories: wetlands and over-moist soils, meadow soils, forest soils, ploughed soils, and desert soils.

Much water in the soil leads to the growth of particular hydrophytic plants, formation of a peat layer, and stable anaerobic conditions. These soils are not used by farmers at all. If the soil is wet but not over-moist, it becomes pasture soil, covered by permanent grass vegetation. It may be used as pasture or as grassland for hay production. This kind of soil is rich in organic matter, but too moist to be used as a ploughed field.

Wet soil might be claimed by agriculture through drainage. However this often leads to soil depletion. Reducing the groundwater table exposes the soil, as it becomes drier, to air and thereby oxygen. This leads to an extensive microbial activity, which depletes organic substance in the soil, and release of carbon dioxide and sometimes methane, both greenhouse gases. In addition this so-called mineralisation of the soil, nutrients are released which may leak to run-off water, and contribute to eutrophication of rivers and lakes. The volume of soil is diminishing and as a result the surface comes closer to the groundwater, and renewed drainage is often needed to allow continued cultivation. In this way the substantial investments in drainage operations become less successful and is sometimes questioned as not economically defendable. Drainage of soils in the Baltic Sea region is further discussed in Chapter 7.

Outlook
Box 18.2

Desertification vs. land reclamation

Deserts are land areas that lay barren due to lack of vegetation. Desert areas of the world are found where the climatic conditions lead to lack of rain or very little rain, as in the tropical areas at 20 to 30 degrees North and South and areas in rain shadow. The largest desert area is the Sahel in Africa. Sahel areas includes the Sahara desert and the Libyan and Nubian deserts, with a total surface of 8.5 million km^2.

The deserts of the world are expanding. This is due to many factors including natural climate variations. However it is clear that human activities also contribute to this desertification. Thus overgrazing in areas close to the desert border destroys vegetation, harvesting of fire wood removes trees in arid areas and leads to loss of the vegetation cover. Finally the barren soil is lost through wind erosion and the area then becomes infertile desert. In the years 1968-74 this led to the death of millions of cattle in the Sahel area. So called "dry farming" (cultivation of dry-resistant plants without irrigation) may also lead to desertification, as the ground is then left without vegetation during long periods.

Desertification has also occurred in industrial countries during some periods. Parts of southern Sweden (Skåne and Halland) and Denmark (Jylland) have experienced expanding sand areas and migration of sand dunes, mostly in the 18th century. In the 1930s, after several unusually dry years, part of the agricultural soil in the US midwest was lost through wind erosion (the "big dust bowl" in 1934). Some 300 million tonnes of soil was lost then and moved some 2,400 km by the wind. The reason was not only the climate but also overgrazing and expansion of agricultural land.

Desertification is a major concern worldwide. In 1994 the "United Nations Convention to Combat Desertification" was signed. Since then the efforts to implement projects to improve land management in arid and semiarid areas have intensified. The efforts include e.g. tree planting to bind top soil and agroforestry which allows organic substances in the soil to build up. Measures that help households in the areas to e.g. cook with less firewood are also important.

Drier soils need irrigation to be productive. Irrigation is on a global scale more common than drainage and is the largest water consuming activity, accounting for some 80% of water use. With proper irrigation schemes, desert soils may also be used for agriculture.

Contamination and pollution

Soils are often damaged by industrial activities and by the infrastructure it supports. Production facilities that contaminated soil include metallurgic factories, petrochemical industries such as factories for paints or pharmaceutics, petrol stations, car washing stations, leachate from landfills that hold solid waste (either municipal or industrial), and wastewater sludge. Difficult pollutants include hydrocarbons such as benzene, toluene and in general PAH, polyaromatic hydrocarbons and chlorinated hydrocarbons, such as PCB, oil used for a variety of industrial purposes over several decades, and heavy metals in e.g. battery production.

There are many examples. In southern Sweden a former factory for carbon copy paper turned out to have used extensive amounts of PCB, that are now leaking to the nearest water course. In Stockholm the new building for the Swedish Environmental Protection Agency, EPA was to be built on the site of the former gas works of the capital. The soil was heavily polluted by creosote, a mixture of aromatics containing aromatic hydrocarbons. On another site a former factory for cadmium nickel batteries had been storing metal deposits. Now the soil is badly contaminated with cadmium. All these sites were remediated at a high cost.

In the former communist states of Central and Eastern Europe the former bases for the Soviet army have large areas of badly contaminated soil. Contamination includes spilled petrol for aeroplanes and solid fuel for rockets. In some agricultural areas there are also storage places for pesticides with high concentrations of these substances in the soil.

Remediation of contaminated soil

Objectives and limitations of soil remediation

Remediation of contaminated soils is normally a difficult and expensive operation. It is however often of high priority and is thus undertaken in spite of costs. Soil contamination is very often responsible for groundwater contamination and can, therefore, create an even more challenging problem to solve if not addressed. Thus, the *intent of soil remediation* is two-fold:

- to eliminate the exposure of humans and other living organisms to the contaminants, and
- to eliminate the source of contamination to groundwater.

The overall objective of the remediation is always the protection of human health and the environment.

No matter what the chosen soil remediation method is, a crucial factor is *the degree of cleanup* that must be achieved to reach the goal of protecting human health and the environment. This question is often referred to as the "how-clean-is-clean" question. Due to the lack of definitive studies on the health risk associated with exposure to the various chemicals that are found at these sites, it has often been impossible to determine to what levels soils have

Figure 18.5. **Contaminated soil.** Contaminated soil is typically found in sites of previous chemical factories, gas plants, storage sites for oil or gas, etc. The soil has to be remediated to allow the construction of new areas for housing or service. Here, in central Berlin, an enormous building activity has characterized the city since the early 1990s. (Photo: Lars Rydén.)

to be cleaned in order to achieve the set protection goals. Simply requiring that all cleanups achieve background concentrations of soil contaminants has been difficult to achieve and very expensive. Increasingly, policy makers, health risk managers and epidemiologists are using *risk assessment techniques* based on site-specific data and circumstances to determine appropriate cleanup levels.

The *technologies* available for soil remediation are numerous. Remedial activities can include the removal of the contaminated material and its safe disposal and/or on-site treatment or destruction or containment. Removal technologies include excavation or dredging. On-site technologies include destruction, treatment, extraction, or containment. Remediation technologies of contaminated soils include removal and off-site disposal, removal and on-site treatment or destruction, or containment.

National programs for soil remediation

Several countries have initiated national programmes for soil remediation. In Sweden the EPA is presently reviewing all old landfills, several of which are leaking to the surrounding surface and groundwater, old tanks for oil and gasoline which were often subsoil on e.g. gas stations and industries, and older industrial sites.

The most extensive soil remediation program in the world is the US Brownfields program. Brownfields are abandoned, idled, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination. Expected benefits of the Brownfields initiative in affected communities are a cleaner environment, new jobs, an enhanced tax base, and a sense of optimism about the future.

A key to the Brownfields program is minimizing the fear of liability of contamination for new owners of Brownfields sites. Many states in the USA have established mechanisms to protect buyers and lending institutions against such liability. Another key to this program is the planned continued use of Brownfield sites for industrial purposes. Usually, residential use of a site produces exposure risks that are up to three orders of magnitude greater than continued industrial use. This is due to the different scenarios about how and where humans would be exposed to contamination. The list of acceptable

Brownfields

Brownfields are abandoned, idled, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination. Brownfield sites are decontaminated to allow new uses, for industrial and residential purposes, and to avoid liability of new owners.

Figure 18.6. Removing soil. The most direct means for remediation of a contaminated site is to remove the contaminated soil and deposit it in a safe way. (Photo: Lars Rydén.)

remediation technologies is therefore broader at Brownfield sites than at sites that need to be restored to residential use cleanup standards.

Most state environmental agencies in the USA are adopting a process called the "Risk-Based Corrective Action" (RBCA) to evaluate and select remediation technologies for state-owned sites. This process was developed by the American Society for Testing and Materials (ASTM). RBCA integrates site assessment, remedy selection and site monitoring through a tiered approach involving various levels of data collection and analysis. Source areas of chemicals of concern are first identified in the initial site assessment. Potential human and environmental receptors, as well as potentially significant transport pathways are also identified. A classification of sites is then conducted based on the urgency of the need for remediation. This need may vary from immediate action required to action required in more than two years, to no action at all. A site may qualify for quick regulatory closure or require a more detailed evaluation. Standard exposure scenarios with reasonable maximum exposure assumptions and toxicological parameters are used in determining risk. When there is a possible risk to human health, a cleanup of the site may be decided or a more detailed site risk evaluation conducted.

Both the Brownfields programs and the RBCA programs usually include some form of site remediation. In the western world, in general, the technology selection process uses selection criteria for remediation technologies. These criteria range from government regulations to economics, to public relations and process technology. These criteria are weighted differently at any given site based on the level of regulatory enforcement, available cleanup funds, public awareness and technological know-how. Very often, certain technologies are not considered because of their cost. Other times, regulatory enforcement is not strict and remedy selection is not appropriate. In many cases, public awareness can help ensure that contamination problems are dealt with properly.

Financing soil remediation projects

Remediation is often very costly. When comparing environmental investments to assure water protection, flue gas cleaning, and soil remediation, the latter is becoming the dominating one in both western and eastern countries.

In several countries special funds have been constructed to finance remediation projects. The funds are built up from fines from former industrial owners, who are legally required to pay at least part of the clean up operations, as well as state money. In Sweden, the EPA handles the financing while in Poland the *Soil Fund* has a similar construction. In the US the so-called *Super Fund* with several hundred billion dollars nation-wide finances many projects.

The U.S. Environmental Protection Agency (EPA) firmly believes that environmental cleanup is a building block to economic development, not a stumbling block – that revitalizing contaminated property must go hand in hand with bringing life and economic vitality back to the community. The EPA's Brownfields Economic Redevelopment Initiative empowers states, localities, and other agents of economic redevelopment to work together in a timely manner to prevent, assess, safely clean up, and sustainably reuse Brownfields. The large investment in soil remediation is thus considered worth the cost.

Remediation technologies – soil removal and groundwater protection

The most direct approach to soil remediation is *excavation*. If enough material is removed, cleanup goals can be achieved. Excavations are usually conducted using earth-moving equipment. Additional specialized equipment is necessary in sites that contain buried drums of hazardous waste.

The waste material that is excavated is either treated onsite and redeposited or transported to a treatment, storage, and disposal facility. The waste material can also be sent to specially designed and monitored hazardous waste landfills. These landfills should be located in geologically stable areas away from environmentally sensitive receptors. However, even the best-designed landfills could develop leaks that may threaten the environment. Synthetic liners could be installed improperly or punctured during installation. Burrowing animals can also puncture these liners and create a conduit for percolating water to contact the waste material. Therefore, it may be unwise to dispose of contaminated soil in a landfill because the landfill itself may become a threat to public health and the environment.

Other in-situ remediation technologies try to control groundwater contamination that results from soil contamination. These technologies include *groundwater pumping and treating*, which is the traditional method of remediating groundwater. It is a costly method because it requires pumping water for years and sometimes decades to reach acceptable contaminant concentration levels, due to contaminant mass transfer limitations. Another technology is *soil vapor extraction*. It removes contaminants from the unsaturated soil zone by pulling a vacuum. *Bioventing* uses a similar approach to enhance aerobic biodegradation of contaminants in the unsaturated zone. Another groundwater treatment technology, *air sparging*, is used to volatilize contaminants in the saturated zone and enhance aerobic biodegradation.

These technologies, as well as a variety of other physical and chemical methods, address the real issue behind soil contamination. This issue in none other than the protection of valuable groundwater resources. Very often, groundwater problems persist after the source of the contamination has been removed because many contaminants such as heavy metals and chlorinated hydrocarbons are very persistent in the environment. Once these contaminants enter groundwater, it is often impossible or too costly to use excavation methods for cleanup. Moreover, current in-situ groundwater remediation technologies are not efficient enough to clean up groundwater due to soil heterogeneity. Remediating soils in these cases may be futile. As a result, some groundwater resources may be irreversibly lost. Thus, it is imperative to prevent such contamination so it does not occur in the first place. It is much easier to prevent these problems than to solve them.

Figure 18.7. Old filling stations are sites where the soil is routinely monitored for chemicals before new uses. Here the soil under a previous gas station is beeing removed for a new residential house. (Photo: Lars Rydén.)

On-site containment

The purpose of on-site containment methods is to prevent migration of contaminants from the source area to environmental receptors such as groundwater and surface water. Impermeable barriers have to be constructed in order to prevent this migration and to divert surface and groundwater from the contaminant source area. An impervious layer below the contaminated zone must be present for these containment methods to succeed. Examples of containment methods are grout curtains, slurry walls, and sheet-piling cut-off walls.

Grout curtains are composed of bentonite and/or Portland cement and are injected under pressure in soils to create a barrier. The soil formation must be unconsolidated and porous to allow for the proper placement of the injected grout. Staggered lines of holes are drilled before the injection of the grout begins. The injected grout flows through the porous medium between holes to form a continuous barrier. Recent advances in grout technology allow the use of chemical grouts that have a wide range of viscosities. Lower grout viscosities are necessary in instances where soils have low permeabilities

Slurry walls are trenches excavated down to an impervious layer. Depths to 50 meters and widths of 1.5 meter are not uncommon. The trenches are filled with a low-permeability material. A bentonite slurry mixed with the excavated soil or another suitable soil is used to fill the trench. Additives, such as polymers can also be used to decrease the permeability of the slurry and protect its integrity. Cement-bentonite walls can also be used. In this case, the excavated soil is

Methods

Box 18.3

On-site chemical treatment technologies for soil remediation

There are various on-site technologies for managing contaminated soils that have been excavated.

Thermal process

The *thermal process* is commonly used for the treatment of soil with organic wastes. A high destruction and removal efficiency (DRE) can be achieved using this method. DREs of 99.99% have been demonstrated for halogenated, non-halogenated, aliphatic, aromatic and polynuclear organic compounds. Unfortunately, this method does not destroy inorganic material such as heavy metals. Also, emissions from incinerators have to be controlled and managed as hazardous waste. DREs include both destruction by combustion and removal by air pollution control equipment. As expected, fuel costs are an important factor in the affordability of this technology.

The excavated waste has to be heated to temperatures as high as 650 degrees C to achieve desorption of the organic waste from the soil matrix. Higher temperatures are necessary to achieve destruction of the organic material in the desorbed gases.

Rotary kiln incineration is the most common method of thermal destruction for contaminated soils. These incinerators can be easily designed to process large volumes of soil. Soils that are contaminated with high concentrations of organic waste with high heating value are good candidates for cleanup using this technology. Cost of treatment varies in the US between 500 to 800 US dollars per tonne.

Chemical extraction

The main physical on-site treatment method for excavated contaminated soil is *soil washing* or *chemical extraction*. Soil washing uses water or other solvents and/or additives such as surfactants or chelating agents to remove contaminants. Cleanup levels of < 1 ppm can be achieved for some contaminants over a wide range of soil contaminant concentrations and soil types. It is a relatively low-cost technology for minimization of waste volume.

This technology has limitations because the contaminants are not destroyed, and the fine particles and solvents must be disposed of, very often as hazardous waste. This technology is chemical specific and does not work on soils with large organic fractions because the organic matter will strongly sorb organic contaminants. Soil washing is usually conducted after the segregation of smaller soil particles (< 60 microns). These particles preferentially bind contaminants because of their large surface area and physiochemical reactivity.

When soil washing is conducted, mobilizing chemicals are mixed with the separated soil in a reactor. Compounds amenable to chemical extraction include volatile organic compounds such as xylene and tetrachloroethene, semi-volatile compounds such as naphthalene, PCBs and PAHs and metals such as arsenic, cadmium, chromium, copper, lead, nickel, and zinc. Commonly used extractants for metals contamination include acids such as sulfuric, hydrochloric and nitric acids, and chelating agents such as EDTA and citric acid. Costs of treatment can go up to 350 US dollars per tonne depending on the soil volume treated.

Soil flushing

The in-situ version of chemical extraction is commonly called *soil flushing*. Chemicals are directly injected in the ground to remove the contaminants. Most applications of soil flushing have been for organic compound removal but soil flushing using only water can be effective in removing metals such as hexavalent chromium because this metal has a high solubility.

The injected solutions for the removal of organic compounds are typically surfactant solutions. *In-situ* systems generally use injection wells to inject extraction fluids in the subsurface and extraction wells to recover the mixture of extraction fluids and contaminants. A wastewater treatment system is usually necessary in order to treat the extracted fluid.

The feasibility of soil flushing depends on site hydrogeology, soil characteristics, contaminant and extractant type and most importantly contact time and efficiency between the contaminant and the extractant in the subsurface. Highly variable soil conditions will result in flushing with low sweep efficiencies. Soils with low permeability will reduce flow of the extractant and contact with the contaminant, resulting in poor contaminant removal. The site hydrology must be known in order to ensure recapture of the extractant fluids after injection. Laboratory studies are often conducted before full-scale application.

Solidification/stabilization

The *solidification/stabilization* treatment of contaminated soil is used to contain contaminants and minimize their release to the environment. This technology, unlike other remediation technologies, does not destroy contaminants. It is intended to inhibit the transport of contaminants through reactions that limit their mobility. This method can be used for treating soils contaminated with heavy metals or other inorganic compounds. Soils must have low organic content for this technology to be successful. Organic material on soil tends to prevent the proper binding of the reagents to the soil matrix.

Solidification/stabilization systems are either organic or inorganic. The most common are the inorganic systems. These systems use binders to cement together contaminants and the soil matrix. Some binders are cement-based or cement/silicate-based and do not require bulking agents. The binders that require bulking agents are cement/fly ash, cement/clay or lime/fly ash binders. Bulking agents such as pozzolans (a material that exhibits cementitious characteristics when mixed with cement) are added to prevent the settling out of solution of the matter in suspension.

The contaminated soil and the binding agents are typically mixed in vessels for up to an hour and transferred by pumps or conveyors to curing areas. Inorganic systems have a relatively low cost (around 70 US dollars per tonne), good physical and chemical long-term stability, are easy to use and have low water permeability. Compounds amenable to this treatment method include metals such as lead, mercury, arsenic, cadmium and antimony and other inorganics such as cyanides and sulfides.

Organic solidification/stabilization systems are mainly thermoplastic or polymerization systems. The thermoplastic systems (or hot melt systems) are primarily bitumen-based. They can be applied to water-laden or oil-laden soils. Water is usually evaporated prior to treatment. Commonly used polymer systems include polyester-epoxy, acrylamid gel, urea-formaldehyde and polybutadiene systems. Organic solidification/stabilization has a high cost because of the energy and the chemicals required for treatment. Very low permeability of the stabilized material can be achieved. However, the material can be unstable in the presence of microorganisms or ultraviolet light. Volatile contaminants can also volatilize from the stabilized material.

On-site chemical treatment technologies for soil remediation

Methods
Box 18.3

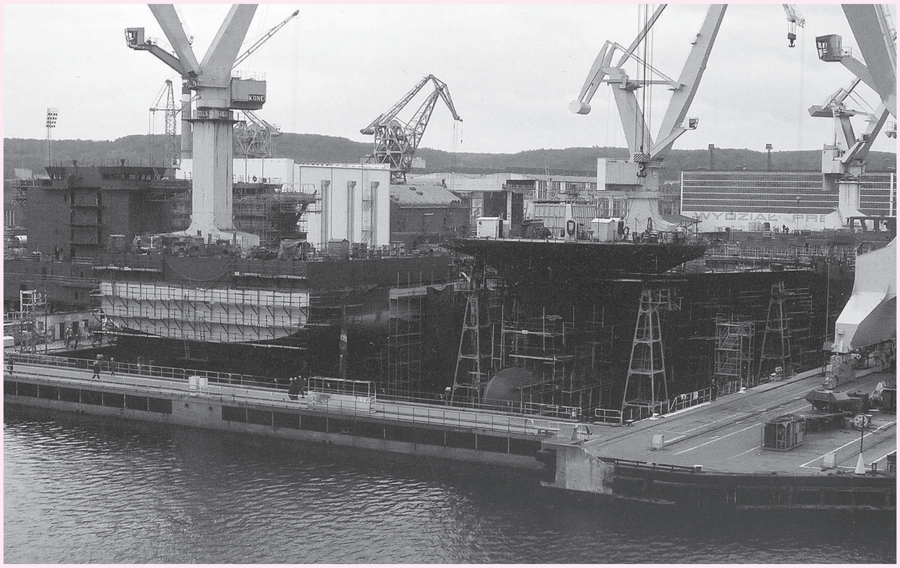


Figure 18.8. Ports and shipbuilding yards. Several major harbours have closed as European ship building decreased and freight systems changed. Old harbours are very attractive water front sites for residential buildings. Well-known cases are Docklands in London and Hammarby Sjöstad in Stockholm, while Gdansk harbour is next in turn. A major cost of construction in these areas is soil remediation. (Photo: Lars Rydén.)

A feasibility study is recommended when evaluating the use of this technology. Bench-scale laboratory testing can be conducted to determine the leachability (whether or not hazardous chemicals can leach out of solidified/stabilized material when in contact with water) and durability of the material. Potential additional costs associated with stabilization/solidification are land disposal costs that can be up to 250 US dollars per tonne in the USA. The stabilized material has to be transported using trucks or conveyors to the disposal site. Cement-like material must be placed in the disposal area quickly because of short curing times. Soil-like material must be placed using procedures that are similar to road building procedures, i.e. the stabilized soil is placed in 20 cm layers with bulldozers and compacted.

Chemical Destruction

Chemical Destruction is another soil treatment technology that can be used to treat certain excavated contaminated soils. This technology alters a contaminant's structure to form new, less toxic compounds. This technology includes hydrolysis, chemical oxidation and dechlorination.

Hydrolysis is an acid or base-catalyzed reaction in which hydrogen-oxygen bonds are broken and new less toxic compounds are formed. It may be used to treat soils contaminated with nitriles, esters and epoxides. Hydrolysis can be an effective treatment method if mass transfer of adsorbed contaminants is not slow. In the soil, contaminants have to diffuse from the solid phase to the liquid phase before the hydrolysis reaction can take place. The hydrolysis rate is dependent on the pH, temperature, solvent composition (water or mixture of water with organic solvent) and catalyst type (bases, acids, heavy metal ions). Hydrolysis is an inexpensive process because the primary reagent is water and alkaline/acidic conditions can be obtained inexpensively.

Dechlorination is a destruction process that uses a chemical reaction to separate chlorine atoms from chlorinated molecules. The resulting products are usually less toxic. The contaminated soil is mixed with an alkali metal polyethylene glycolate (APEG, a proprietary reagent). The chlorinated contaminant is then stripped of its chlorine atoms. Various compounds can be dechlorinated. They include polychlorinated biphenyls (PCBs), chlorobenzenes, organochlorine pesticides, chloroform, methylene chloride and chloroform. Soil properties play an important role in the success of this technology. High moisture can deactivate the APEG and prevent the dechlorination. Also, poorly graded soils that contain clay may be unsuitable for this remediation technique.

Chemical oxidation

Chemical oxidation is a process that alters toxic compounds and forms less toxic daughter compounds. This process has been applied successfully to the treatment of water and wastewater for numerous years but due to the fact that contaminants can sorb to soil, mass transfer limitations may apply and limit the effectiveness of this technology.

Chemical oxidation can be used to treat soils contaminated with unsaturated aliphatic hydrocarbons, halogenated aromatic compounds, halogenated phenolic compounds, sulfides and other organic contaminants. Three major oxidants that are commonly used are hydrogen peroxide, ozone and hypochlorites. Potassium permanganate has also been used recently to treat soils contaminated with perchlorethylene and trichloroethylene, which are common solvents used in degreassing and dry-cleaning operations. One important drawback of using chemical oxidation on contaminated soil is that this process is non-specific. The oxidant will react with any oxidizable compound. If a soil has a high organic content, it may not be practical or economical to treat the soil because of the increase in chemical reagent consumption. Chemical oxidation can be used on-site on excavated soil or in-situ in the subsurface. Low permeability zones and heterogeneities in the soil may limit the effectiveness of this technology, as is the case for all soil flushing technologies.

Amine Dahmani

replaced by cement in the slurry mixture in order to produce a solid and permanent wall. These walls, however, are more susceptible to chemical degradation. Deep-soil mixing is sometimes used to construct slurry walls. Large augers equipped with mixing paddles are used to install these walls. Bentonite and cement are injected in the soil during the auger drilling.

Sheet piling cut-off walls are a series of pilings of concrete, wood or steel that are driven in the ground to an impervious layer to form a cut-off wall. Depths to 35 meters have been reached using this technique. However, this technique cannot be used in rocky soils due to the difficulty in driving the piles. Also, sheet piles are subject to chemical degradation or corrosion that leads to leaks and failure to prevent containment of the contaminants.

Chemical and physical on-site treatment

The preferred method of dealing with contaminated soil is to use on-site technologies for treatment, destruction, extraction, or containment. These include:

- A *thermal process*, commonly used for the treatment of soil with organic wastes. The excavated waste has to be heated to temperatures as high as 650 degrees C to achieve desorption of the organic waste from the soil matrix.
- The main physical on-site treatment method for excavated contaminated soil is *soil washing* or *chemical extraction*. Cleanup levels of < 1 ppm can be achieved for some contaminants over a wide range of soil contaminant concentrations and soil types. It is a relatively low-cost technology for minimization of waste volume.
- The in-situ version of chemical extraction is commonly called *soil flushing*. Chemicals are directly injected in the ground to remove the contaminants.
- The *solidification/stabilization* treatment of contaminated soil is used to contain contaminants and minimize their release to the environment. This technology, unlike other remediation technologies, does not destroy contaminants. It is intended to inhibit the transport of contaminants through reactions that limit their mobility.
- *Chemical Destruction* is another soil treatment technology that can be used to treat certain excavated contaminated soils. This technology alters a contaminant's structure to form new, less toxic compounds. This technology includes hydrolysis, chemical oxidation and dechlorination.
- *Chemical oxidation* is a process that alters toxic compounds and forms less toxic daughter compounds. This process has been applied successfully to the treatment of water and wastewater for numerous years but due to the fact that contaminants can sorb to soil, mass transfer limitations may apply and limit the effectiveness of this technology.

The methods are described in more detail in the Methods Box 18.3. For each technology the destruction and removal efficiency (DRE) should be measured to evaluate the effect. DREs of 99.99% can be achieved in many cases for all kinds of contaminants, including halogenated, non-halogenated, aliphatic, aromatic and polynuclear organic compounds.

Biological soil remediation technologies

Bioremediation is a method that uses microorganisms to mediate the transformation of hazardous chemicals to less toxic or non-toxic compounds. Microbial organisms or their metabolites convert complex substances (known as substrates) to simpler, less toxic compounds. Bioremediation can be an efficient and cost-effective method to treat contaminated soils. There are various bioremediation technologies, ranging from the use of natural bacterial cultures to complex genetic engineering applications that produce specific organisms for degrading specific compounds. Bioremediation is a feasible remediation

Biotechnology for removing metals from soil

Some plants species, metallophytes, are known for their high metal burdens. They are able to grow and germinate on soils with a high concentration of heavy metals or on soil contaminated with metals from industrial processes. They are often used for revitalisation of artificial metal-containing waste dumps with low pH and strongly reduced access to biogenic minerals. In such places other plant species have strongly reduced growth or are unable to survive. Some metallophytes, which accumulate metals in their tissues, are successfully used in *phytoremediation* technologies to clean soil from metals accumulated during industrial activites.

technology if the microorganisms are capable of acquiring new metabolic pathways and synthesizing appropriate enzymes to achieve the desired degradation within reasonable time frames. The microorganisms needed for the biodegradation process can either be present as a suspension in the liquid phase or attached to the solid phase. In the liquid phase, microorganisms are suspended in water and consume the dissolved chemical compounds. The chemical compounds (contaminants) diffuse through the cell wall of the microorganisms and are consumed for biological growth and energy. In soils, microorganisms may attach to the solid phase, thus forming a biological film on the soil surface. In this case, contaminants may travel through the biological film and then adsorb on the cell walls before being consumed.

Bioremediation processes for excavated contaminated soils include biopiles, landfarming, composting, and slurry reactors. *Biopiles* are created by spreading

Case
Box 18.4

Environmental restoration through bioremediation

A heavy industry in Czechowice-Dziedzice, Poland

Czechowice-Dziedzice is a small town in southern Poland dated from the XV century. There is a concentration of heavy industry in this small area. A main employer is the more than 100 year old Czechowice Oil Refinery, where recently more than 1,400 people worked. Crude oil is refined there by the use of a catalytic cracking process. The waste stream from the refinery process, a thick semi-liquid substance, empties into lagoons which contain millions of litres of a mixture of various hydrocarbons and other undetermined substances.

Remediation projects

In co-operation with a series of American companies specialising in modern remediation technologies the Institute of Ecology of Industrial Areas, Katowice, started a project sponsored by the US Department of Energy

The project has three components:

- **Site characterization** – in two phases where all qualitative and quantitative analysis were conducted and data were collected for the preparation of the second stage.
- **Risk assessment** - risk-based evaluation as a critical tool for guiding environmental management decisions at the contaminated sites. These evaluations were used for development of site-specific goals for the design and implementation of the remediation system.
- **Site remediation**. The technologies employed here included in-situ bioremediation, which uses the natural cleansing capacity of the environment to degrade hydrocarbon pollutants. In relation to the obtained data from the first phase of the project a mixture of microorganisms making possible a high biodegradation rate of the contaminants were used. This phase of the project is in progress and takes four seasons to optimise the operating parameters during the system performance.

Bioremediation

The bioremediation system consists of a series of injection wells located at the perimeter of the lagoon for bioventing the contaminated vadose zone of the region. Bioventing means that the air and nutrients are injected to indigenous microorganisms in order to stimulate their

Figure 18.9. Soil remediation in Estonia. Former sites for strip mining of oil shale are contaminated by residual petrolium products and a complex mixture of metals, as this site outside Tallinn in 1991. (Photo: Lars Rydén.)

biological activity. The lagoon is filled with dissolved nutrients. Water comes from the refinery process water system with the amended sludge. The process is continued until the sludge has been reduced to a less toxic or non-toxic level. The process is speeded up by stimulating the microorganisms to feed on contaminants.

Methods and bioremediation strategies are planned by Westinghouse Savannah River Technology Centre. The risk based assessment identified 19 compounds consisting of PAHs and BTEX. The final biopile design consists of:

- dewatering and clearing the lagoon to clean clay,
- a 20 cm layer of dolomite with pipes added for drainage, leachate collection, air injection and pH adjustment,
- addition of a 1.1 m layer of contaminated soil mixed with wood chips to improve permeability, and
- planting grass on the surface of the top soil.

An area about one ha in size has been remediated and cleaned up to produce a green zone (Worsztynowicz et al., 1999).

Figure 18.10. Bioremediation. *Berkheya coddi* (Asteraceae) is an efficient nickel accumulator (up to 4% of Ni in dry mass of twigs and leaves). The plant is indigenous in Mpumalanga Province, in the Republic of South Africa where it grows on serpentinite soils. This species is under study as a potential plant for phytoremediation (even phyto-mining!) purposes. (Photo: Pawel Migula.)

contaminated soils on a lined treatment bed. Air and/or nutrients dissolved in water are flushed through the soil pile to optimize the biodegradation of the contaminants in the soil. *Landfarming* is conducted by spreading the contaminated soils on the surface of the ground to enhance natural microbial degradation of contaminants in the soil. This method has been successful in treating petroleum refinery waste in areas where air emissions do not pose unacceptable levels of health risks.

Composting has been used extensively to manage municipal wastewater treatment sludges and is currently being tested to treat contaminated wastes. The organic contaminants are degraded within the compost matrix consisting of contaminated soils and sludges mixed with sources of organic carbon and bulking agents such as straw, wood chips, and saw dust. The compost piles are usually up to two meters high. The microbial degradation is maintained by optimizing temperature, oxygen, moisture level and nutrient levels in the pile. *Slurry reactors* combine contaminated soil and nutrient-rich water in bioreactor vessels or lined lagoons to form an aqueous slurry where biodegradation occurs. Mixing must be continuous and oxygen must be supplied to enhance aerobic microbial activity.

Before using bioremediation to treat contaminated soils, it is important to investigate the biodegradability of the contaminants. Some contaminants can be completely biodegraded (mineralized). Others may persist and require more appropriate conditions such as a better availability of nutrients and favourable environmental factors (temperature, moisture content, pH). Some contaminants may be recalcitrant and not amenable to biodegradation. The testing could be accomplished using simple batch experiments in a laboratory. Compounds containing highly branched alkyl hydrocarbon chains degrade more slowly than straight chains. Functional groups such as carboxylate and hydroxyl groups on benzene rings can increase biodegradability. Sulfonate, halogen and nitro groups, however, decrease biodegradability. In general, water soluble compounds are more biodegradable than insoluble ones. The chemical groups that are the most biodegradable are esters, anhydride and carbonyl groups. The least biodegradable are epoxide, benzene rings and methylene groups. Some compounds such as trichloroethylene and vinyl chloride can be biodegraded using co-metabolic reactions. These reactions result in the biotransformation of a contaminant by a microorganism that does not gain energy for growth from the contaminant. It is an incidental transformation brought by non-specific enzymes produced by the organism for other purposes. The addition of a carbon source is necessary for a co-metabolic process to occur.

The aerobic biodegradation process is preferred over anaerobic biodegradation because it is a faster process. Operation and maintenance costs are decreased if a process is faster, thereby making aerobic bioremediation more cost-effective.

There are other innovative ways to remediate soils. One of these methods is *phytoremediation*. This method uses plants to remediate inorganic or organic contaminants at the root zone in soils. The advantages of phytoremediation are soil stabilization and minimization of contaminant leaching, aesthetic improvements and low capital costs. Heavy metals can be bioaccumulated in plant tissues. These inorganic compounds are very often vital plant nutrients for growth and development. Plant species can also be chosen to assimilate and decompose organic contaminants such as pesticides and PAHs. Unfortunately, phytoremediation does not work below the root zone or in soils that are too contaminated and toxic for plant or tree growth. Sites with slightly soluble contaminants such as benzene, ethylbenzene, toluene, xylenes, PAHs, chlorinated hydrocarbons, nitrotoluene are the most suitable for phytoremediation. Sites with excess nutrients such as ammonia, nitrate and phosphate as well as sites with heavy metals are also suitable for this technology.

Solid waste

Wastes – right resources in the wrong place

Waste has always been produced by society, however its management has changed through time. In old cities refuse was thrown out directly on the streets. The demand for improved hygiene moved the waste out of cities to the first uncontrolled dumping places. Population increase, growing industrialisation, urbanisation and ecological awareness all contributed to also make this solution to the waste problem insufficient. Waste was seen as hazardous and a threat to human health and the environment. The landfills became better controlled and secured. Concern was also expressed about other waste treatment methods, e.g. incineration.

In parallel there was and is a growing awareness that producing waste is a loss of natural resources. Thus, the main goal of waste management is not to get rid of refuse but to treat it in a way which could save as much resources as possible. The discussion on sustainable development has deepened this aspect. This approach argues that new generations have a right to use the resources that are so freely being taken from the biosphere and turned into waste by us.

Modern waste management is today often seen as part of proper resource management. It includes not only storage techniques but also measures aimed at reducing waste production. Thus, waste is now regarded as part of material flows in society, and it is within the framework of the material flows approach that new solutions to waste reduction problem are sought. Waste is a raw material transformed to a different form.

Solid waste is a quantitatively important material flow (about a tonne per year and person) in the region. In general one-third of the waste is generated by households and two-thirds by industry, however it varies by country (Berg, 1997). In Sweden, industry produces as much as households, while in Poland industrial waste accounts for 90% of the total refuse generated (OECD, 1999).

The material flows perspective

In society natural resources are extracted, used to manufacture needed products, and finally disposed of as waste. This material flow may be linear, when all the source material is transferred from one form to another, which leads to exhaustion of the source stock and accumulation of the sink stock. Thus combustion of fossil fuels leads to exhaustion of the layers of oil, coal or gas

Figure 18.11. A landfill. Modern society produces enormous amounts of solid waste. Earlier much of this ended up on a landfill and contaminated the soil and water in the vicinity. Often this was unregulated as here outside Krakow and as such illegal. Today large efforts are made to recycle most waste and severely reduce landfilling. (Photo: André Maslennikov.)

Table 18.2. The composition of solid waste. The data are from landfills in Liepaja, Latvia; Järvamaa County, Finland; Warsaw, Poland; and Borås, Sweden (all units in percent). (Source: Berg, 1997.)

Component	Liepaja	Järvamaa County		Warsaw	Borås	
		Spring	*Fall*		*Domestic*	*Industrial*
Compostables		65	76		53	5
Food	6			23-31		
Bones		2				
Paper, cardboard	20	11	10	13-22	23	21
Textiles	8			3-6	1	1
Plastics	10	4	1	5-12	6	11
Wood	30	3	2			15
Leather		10				
Misc. burnable		2	5		10	18
Glass	5*	7		6-12	4	2
Metals	8	2		3-5	2	7
Misc. "inert"		6	6		2	17
Particles < 1 cm				8-25		
Other	1			8-20		
Total	100	100	100		100	97

** includes ceramics*

and the accumulation of carbon dioxide, a "molecular waste," in the atmosphere as a consequence. But the material flow may alternatively be circular, in which the materials return to the source stock.

Very often the main, intentional flows caused by man are accompanied by unwanted by-flows, e.g. contamination of metal ores by other metals, production of solid waste when extracting metal ores. All the material by-flows which are unavoidable and connected to extraction of useful materials but are not incorporated in the extraction product are part of an "ecological rucksack." It means that besides the wanted material an overburden in form of e.g. rock is produced, which often constitutes the major part of materials extracted, e.g. the grade of copper ore can be as low as about 0.3%. In many cases several material flows are needed to accomplish a task, e.g. manufacturing of a product, however they are not incorporated in the final product, e.g. water and air in technological processes, and are therefore included in the rucksack.

Material flows in society are very complex and interconnected. In order to use a resource an infrastructure has to be built first, which involves, of course, new material flows for the needed equipment and its maintenance.

Waste prevention methods result in a lower amount of waste produced and force industry to implement more suitable resource management. Waste minimization may among other things lead to modernisation of technological processes, recycling of materials used in processes and introduction of cleaner technologies. Lower consumption of raw materials has also been proven to be economically profitable.

Solid waste and waste/soil connections

There are many definitions of solid waste, depending on the country. Here solid waste is understood as any movable material that is perceived to be of no further use and that is permanently discarded (Jackson & Jackson, 1996). It is, however, important to stress that what is for the time perceived to be of no further use may be regarded differently in another situation. Very often material is defined as waste when the management system is underdeveloped or failed. There is also the technical development to consider. What cannot be reused today may become a resource tomorrow due to development of new technologies.

Solid waste is generated during raw materials extraction, production processes, energy generation processes, commercial activities (by shops, offices and other small businesses), and in households. Solid waste may be divided in many ways depending on the criteria applied (by source, fraction, hazard, etc.). For the needs of this chapter solid waste is classified by source. However, where required a description of composition is given.

The contamination of soil is mostly connected to improper methods of waste handling. In too many old industrial sites unwanted materials were simply deposited in the vicinity of the plant. In former times hazardous waste was collected in barrels that were deposited or even buried in the ground. Oil spills and spills of other chemicals contaminated the soil. Construction materials or production were stored on the ground and leaked to the soil. Today such habits have been discontinued if for no other reason due to the fines that result if the sites are discovered.

Landfills are also more often than not contaminating soil and groundwater in their vicinity. In Sweden, to take one example, 3,000 old landfill sites all over the country are presently being examined to determine if they are leaching to groundwater.

Table 18.3. The composition of typical urban refuse in industrial countries. (Source: Jackson & Jackson, 1996.)

Component	% by weight
paper	35
garden waste	16
food waste	15
metals	10
glass	10
plastic, rubber, leather	7
rags	2
miscellaneous	5

Solid waste produced by mining and industry

Mining and quarrying waste accounts for the largest amounts of solid waste in the region, such as in Poland 70% and in Finland 66%. The main natural resources mined are metal ores (Sweden, Finland, Poland), aggregate materials used in building and road construction (all countries), and fossil fuels, i.e. hard coal (Poland), lignite (Poland, Eastern Germany), oil-shale (Estonia and western Russia) and peat (many countries) (Jackson & Jackson, 1996).

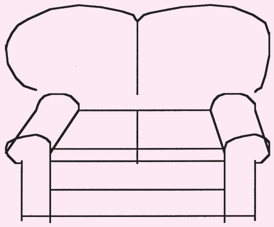
The main waste generated by mining is soil and rocks overlying the desired minerals. If the processing of material extracted is carried out on the site then the waste may also include material contaminated by different pollutants depending on the resource, e.g. heavy metals present in metal ores. This is also characteristic for the waste from oil-shale mining contaminated by heavy metals and phenols (Morovi & Tuschy, 1997).

The amount of solid waste depends on a number of factors including the nature of the mineral in question, the method of extraction required, and the

Case

Box 18.5

Environmental life-cycle assessment of a couch



Many consumer items have a complex life history with a range of materials involved in its production, maintenance, and waste phases. Here you will find the materials used for the production of an ordinary couch, and the pollutants emitted during its life-time. (Source: Antonsson et al., 1991). In summary a couch influences the environment by contributing to:

- the greenhouse effect (emission of carbon dioxide and methane),
- ground level ozone (emission of hydrocarbons),
- depletion of stratospheric ozone (emission of trichloroethane in the glue),
- acidification (emission of NO_x and SO_2), and
- dioxin emissions.

Materials needed for manufacturing a couch:

13.5 kg particle board
4 kg board
1.3 kg millboard
0.5 kg plywood
17.5 kg pinewood
8.3 kg polyurethane foam
7 kg cotton
2 kg Fe (incl. 0.3 g Zn and 10 g Mn)
50 g PVC
4 g nylon
450 g polyester
paint and glue

Pollutants emitted from a couch during its "life-time:"

2 mg press gases
20 mg acetone
15 mg hydrocyanic acid
1.2 g acetic acid
110 mg methylketone
8 g xylene
0.3 g hydrochloric acid
130 g terpenes
1.4 g ethanol
27 g carbon monoxide
8 g carbon dioxide
3 g buthanol
2 g sulphur dioxide
37 g nitrogen oxides
3 g buthyl acetate
680 mg formaldehyde
1.2 g ethylenglycole acetat
2.3 g methyl-isobuthyl-keton
40 mg isobuthyl alcohol

Alicja Andersson

Table 18.4. Total consumption emissions of cadmium, chromium, and lead in Sweden by major category. (Source: Bergbäck, 1992.)

Metal	Total emission (tonnes)	Period studied
Cadmium	**900**	1940-1990
emitted from:		
Phosphorus fertilizers	41%	
Plating	21%	
Batteries	14%	
Pigments	13%	
Stabilizers	11%	
Chromium	**38,500**	1920-1980
emitted from:		
Pigments	83%	
Steel products	4%	
Tanning	4%	
Plating	2%	
Other uses	7%	
Lead	**159,000**	1880-1980
emitted from:		
Ammunition	31%	
Petrol	28%	
Other consumption	41%	

grade of material extracted. Both excavation of metal ores and hard coal mining result in huge waste deposits, while the amount of waste produced by extraction of aggregate materials varies greatly depending on the material extracted. Sand and gravel are removed directly, while extraction of asbestos produces as much waste as metal ore extraction (Jackson & Jackson, 1996).

Mine waste is usually disposed of on land near the mine facilities, often forming large waste heaps. Mine waste can in some cases be reused, e.g. for landscaping, construction of dwellings and roads, to reclaim areas degraded by mining and to refill mine pits (OECD, 1995).

Solid waste from energy generation. Both the quality of fuel used and the combustion technology determine the type of waste generated. Even the cleaning technology applied influences the type of waste produced. A low quality fuel, e.g. coal, may have a high sulphur contamination (more than 1.2%) and a high amount of rock material (even up to 30-35% of coal) (Nowicki, 1993).

In general the solid waste from fossil fuel combustion include residual solids, i.e. ashes (furnace bottom ash and pulverised fuel ashes which is collected as a particulate from the flue gases) and products from fuel desulphurisation (wet or dry cleaning products or mixture of fly ashes with desulphurisation products) (Lundgren & Elander, 1986).

Desulphurisation means that the fuel is cleaned by separation of the organic fuel from the inorganic ash, forming mineral impurities. Both the fuel itself and the flue gas may be object of the cleaning process. To both, limestone ($CaCO_3$) is added as an alkaline absorbent. The final products of the cleaning process are calcium sulphate ($Ca SO_4$) or a high quality gypsum ($CaSO_4 2H_20$). Solid waste generated by the energy sector may be used as building material, and after some processing the gypsum from desulphurisation may be used in e.g. plasterboards.

Construction industry. The refuse generated by the construction industry includes all solid materials used for construction of buildings, such as wood, various types of bricks, insulating materials, hollow bricks, glass, plastics, metals, etc. Some of the materials, especially those coming from demolition of old buildings, may be hazardous partly because of the construction material used (e.g. asbestos), partly because of the activity performed in the building (e.g. contamination of building walls and equipment due to industrial processes).

Table 18.5. Environmental impact of some consumer products.

Consumption Area	Product/Activity	Substance	Environmental Impact
House & Home	Cleaning and washing substances	Phosphates, bleaching, agents, chlorine comp, incl. AOX (organic chlorine compounds), optical whitening agent.	Eutrophication, harmful to water organisms.
	Cooling, Refrigerators	Freons	Ozone layer depletion.
	Kitchen equipment	Metals (Al, Cu, Fe).	Harmful to organisms when released.
	Decorations (furniture, decorative elements, etc.)	PVC, polyurethane, metal pigments in glass, plastic and ceramics (Cr, Pb, Cd).	Harmful to organisms.
	Batteries	Metals (Cd, Ni, Pb)	Harmful to organisms.
	Heating and energy	CO_2, NO_X, SO_2.	Greenhouse effect, acidification.
	Packages		Waste mountains, Transport of raw materials, e.g. Al. Environmentally dangerous substances in the plastics.
	Cosmetics	Various chemicals	Harmful to organisms.
	Thermometers	Hg	Harmful to organisms.
Leisure & Hobbies	Garden	Pesticides, herbicides, fertilizers.	
	Hunting	Pb	Poisonous to organisms (birds) when ingested, accumulation in soil.
	Boats	Tin compounds, solvents.	Harmful to water organisms and humans.
	Painting	Metals as pigments (Pb, Cd).	
Transport	Fuel	CO, HC, NO_X,	Greenhouse effect, acidification.

Figure 18.12. One of two solid waste collection stations in Uppsala city. The stations are an efficient method of sorting and collecting large amounts of waste ranging from electronics to building materials. (Photo: Lars Rydén.)

Many fractions of waste produced by the construction industry may be reused, e.g. bricks, to build new houses or wood for energy production. The fractions must be, however, free from contamination and separated from each other. This is specially important in countries with a high production of construction waste, e.g., Germany (OECD, 1993). The fractions that cannot be reused are disposed of on land at municipal landfills. However, the contaminated waste material has to be treated as hazardous waste and disposed of according to regulations of that particular type of refuse.

In the Baltic region, the question of how to manage demolition waste became very important after the withdrawal of the Soviet army from the former socialistic countries. The heritage in form of old useless equipment and buildings, and contaminated soil is still largely waiting to be taken care of. Also the demolition and treatment of old, heavily contaminated industrial buildings requires a new approach, e.g. the old chemical plant in Tarnowskie Gory in Poland.

Municipal waste

Municipal waste includes commercial waste and waste generated by households. The fractions found in the municipal waste are common for all countries, however their proportion depends on the source (commercial versus residential) and the time of the year. The typical composition of waste (Table 18.2) is about the same in the entire Baltic Sea region (Berg, 1997). The differences depend mainly on packaging consumption.

The basic level of solid waste management consists of waste collection, landfilling, and incineration, while recycling is considered a second level management method.

Waste collection. Collection of refuse is a first step towards a good waste management. The municipalities are obliged to organise waste collection from the households. The collection system functions well if it is offered to a high percentage of a population and if it creates a good base for further waste management, e.g. by a separate collection of different waste fractions. Introduction of a waste collection system is different in different countries. In Sweden and Norway almost all inhabitants are served by the collection system, in Czech Republic over 80%, in Finland 75% (GUS, 1997), in Poland only 55% of the population (OECD, 1995). People who are not served by the system are expected to take care of the waste by themselves. This may, however, result in “wild” dumps, which was a common phenomenon in Eastern Europe. The system of municipal solid waste collection is technically similar in the entire region, but the management has developed in different ways (Berg, 1997).

Solid waste management

Waste and waste management methods

The easiest way of solving the waste problem is to prevent its generation. However the refuse that eventually is produced has to be managed in the most sustainable way regarding resource management, i.e. refuse has to be used as much as possible before it will be finally deposited. According to EU's recommendation the hierarchy of waste treatment methods is the following:

- waste minimization, waste prevention,
- reuse,
- recycling,
- recovery for energy, and
- deposition.

The goals for waste management policy are set up by an appropriate administration in every country. A set of regulatory instruments, or tools, is available to achieve the goals. They include legal tools, such as banning a waste management method, e.g., improper dumping, and various economic tools, such as taxes for depositing waste on landfill.

Solid waste management includes not only methods for waste storage (i.e. end-of-pipe solutions), but also measures aimed at reducing the amount waste produced, i.e. waste minimization or waste prevention. They are often addressed to manufactures and have proved to be economically profitable and are the following:

- modernisation of technological processes,
- introduction of cleaner technologies, and
- recycling of materials used in processes.

Waste prevention programmes also comprise rules to be applied to a product:

- use less material for a service (by using it more efficiently, increasing its quality or making things smaller and multifunctional),
- make the material last longer (by improving quality, better protection, better maintenance, and higher repairability), and
- use the material again (by reusing the goods itself or the materials in it)
- substitute a harmful/scarce/non-renewable material for a less harmful/ scarce/ or renewable material.

Figure 18.13. Recycling of glass bottles. Containers of many kinds are returned for reprocessing or refill. This is made efficient through the return and deposit system, through which the consumer is paid for returning the bottles. (Photo: Inga-May Lehman Nådin.)

Reuse and recycling

Reuse of material or goods and *recycling* means collection of valuable fractions of refuse which can be later used as raw material for manufacturing of new products, closing the flow of materials in society as the same asset or material is used again and again. In addition to improving the material flows in a society reuse and recycling obviously reduces the need for disposal capacity and correspondingly diminishes emissions from landfills and incinerators. It also reduces energy use and emissions related to extraction and manufacturing as recycled materials are used. The use of recycled material in production contributes also to reduction of both energy consumption and emission discharges related to extraction of raw materials and manufacturing of products.

Recycling using *natural cycles* include e.g. composting where organic material is returned to the soil, or use of sludge from waste water treatment plants to fertilize fields. *Technical cycles* include e.g. return of lead batteries from cars to be renovated

Case
Box 18.6

Uppsala waste incineration plant for energy production

Waste incineration

Vattenfall Värme Uppsala AB provides most of Uppsala's 180,000 inhabitants with district heating. Ca 40% of the heat is generated by municipal waste incineration. In addition to local waste, waste is "imported" from approximately 25 municipalities in Sweden and one in nearby Finland (Åland). In 2001 235,000 tonnes of separated waste was processed. This is expected to increase to 375,000 tonnes, an increase by 60 per cent, by 2004.

The waste incineration capacity is expanded for several reasons. From 2002 deposition of combustible waste on landfill is not permitted under EU regulations; remaining depositions are taxed heavily. The municipalities in EU countries will thus expand their systems for most types of recycling, composting etc., and also for waste incineration.

The waste incineration in Uppsala has to comply with environmental regulations as defined in a special permission (concession) issued by the environmental authorities. The company has in addition implemented environmental management according to ISO 14001.

The ashes from the incineration are delivered to a waste facility managed by the technical office of the municipality. However, the aim is of course to recycle as much as possible of the bottomslag.

Technology of incineration

After weighing, the waste is collected in a bunker, then moved by an overhead crane, into the inlet of the furnace. The waste is then combusted on the grate, which moves the waste gradually forward under good mixing.

The *primary air,* is now added in excess and often, at least partly, preheated to improve the energy balance in the first part of the incinerator.

The ashes and slag from the incinerator fall down into a *bin* filled with water. From there, it's are transported with a belt to a container or bunker, and after that to a special *landfill*.

The flue gases from the incinerator are guided up to a secondary incineration chamber where secondary air is added. The gas passes here at about 1000 °C for a number of seconds before it continues to the convection part of the boiler. In the boiler the heat energy from the gases is transmitted to hot water or water vapour.

Figure 18.14. Diagram of the waste incineration process. (Courtesy by Vattenfall Värme Uppsala AB.)

Figure 18.15. Waste-claw (Courtesy by Vattenfall Värme Uppsala AB.)

Flue gas cleaning

The flue gases are cleaned in a special *flue gas cleaning device.* Since the demands on the effectiveness nowadays are very high, the cleaning devices often needs a bigger building volume than the rest of the waste incineration plant. Several different types of cleaning system are used.

Most of the fly ashes and dust are separated in an electrostatic filter. An economizer takes down the gas to 140 °C and is an extra heat exchanger in the ordinary furnace system. Then a cooler sprays water into the gases so the temperature drops to 60 °C. Acid gases in the flue gases, HCl, HF and SO_2, are dissolved in the water. Dust and particles that contain heavy metals also get caught in the water and metallic mercury condenses. Also dioxins and other compounds get caught in the water.

Gas treatment - condensation

The water-saturated gas goes through a condensing reactor where the temperature is taken down to about 40 °C. Then the dry gas is heated (with low need of energy) in order to prevent direct condensation of the gases when they are let out of the stack. The acid gases are neutralized by blowing in powdered limestone into the gas stream, followed by dust separation with a textile filter, in which also mercury is separated.

Table 18.6. Emissions from the Uppsala incinertion plant

	Limit (Permit)	Measured emission
To water		
Condense water	<150,000 m³/year	139,649 m³/year
pH-value	>7	>8.1
Dioxin	<0.1 ng/L	0.0045 ng/L
Hg	<10 µg/L	<3.0 µg/L
Pb	<50 µg/L	<15.0 µg/L
Cd	<10 µg/L	<2.9 µg/L
Cr	<50 µg/L	<6.6 µg/L
Ni	<50 µg/L	<16.9 µg/L
Zn	<600 µg/L	76.4 µg/L
Co	<10 µg/L	<5.0 µg/L
To air		
Dust	10 mg/m³	<1 mg/m³
HCl	100 mg/m³	<1 mg/m³
HF	<0.1 mg/m³	
SO_2	50 mgS/MJ	<1 mg/m³
Hg tot	0.03 mg/m³	<0.0055 mg/m³
TEQ Dioxin	0.1 ng/m³	<0.005 ng/m³

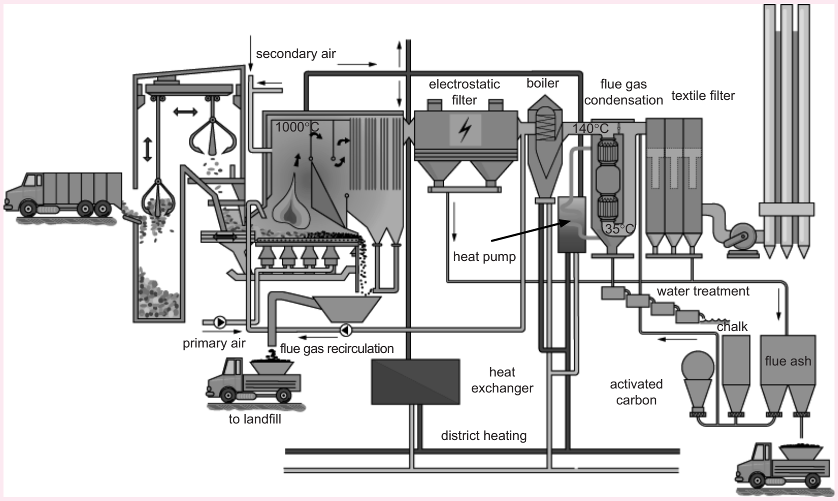


Figure 18.16. Recycling scrap iron. Scrap iron is returned and paid for. This company paid 80 SEK (8 Euro) per tonne in 2002. About 50% of iron is made from scrap iron, which accounts for more than one million tonnes yearly in Sweden alone. (Photo: Lars Rydén.)

and reused. In the case of toxic material, such as lead, the technical cycle needs to be very efficient to avoid an unwanted environmental impact. It can be shown that this is possible to achieve, that is a return rate above some 99.9% is manageable with the proper incentives (Karlsson, 1997).

The most classical example of reuse is glass bottles that may be refilled. Also in the technological processes waste can be fed back into earlier material-processing steps, e.g., copper scrap in the manufacturing of copper wires. Although the socialist system is often associated with wastefulness of natural resources in industry, a system for reuse of packaging from consumer products and recycling of some goods was well developed in the eastern countries of the Baltic Sea region. Milk, cream, and other diary products as well as drinks were available in glass bottles used for refilling. Recycling systems included collection of paper, metal scrap, and textiles. By using a return compensation on e.g. aluminium cans the recycling systems may be efficient, up to some 75%.

In order to be used in production the materials have to be cleaned, i.e. not mixed with waste. Thus, recycling must be based on source separation. This is particularly important in the case of municipal waste because the separation of the valuable fraction from the mixed waste is an impossible task. In case of industrial waste the separation may sometimes be successfully done in the later stage.

In general municipal waste consists of 75% recyclable fractions, i.e. glass, paper, metals, and plastics. Up to 50% of the solid waste produced by households is food rests, which may be composted and reused in the garden.

In the Baltic Sea region recycling is growing in importance. Germany has introduced a recycling programme (DSD) that obliges manufacturers and distributors to take care of the packages used for their products. The recycling schemes that were in place in Eastern Europe during the communist period have however collapsed. The reason for this break down is the new price structure for secondary materials (OECD, 1995). Industrial waste is also being recovered: in Finland about 58% of the industrial waste produced (OECD, 1997), and in Sweden 47% (mining waste included) (Naturvårdsverket, Environmental Protection Agency, 1996).

Incineration

Incineration methodology is applied to both municipal and industrial (organic hazardous) waste. The refuse is burned in combustion facilities at temperatures of 800-1,400 degrees C or more. The hazardous waste is completely destroyed because of the high temperature and long retention time. There are different

Buying and selling solid waste

Development of waste management has created an enormous flow of solid waste in societies. This includes paper, glass, and household waste, but also scrap iron, scrap copper, etc. While several years ago this most often ended on a landfill today it is a resource. Scrap paper is used together with virgin fibres (about half of each) for new paper production. Paper factories thus buy return paper and of course for the cheapest price, wherever it is found. Iron works use a substantial amount of scrap iron when producing new material. This is an older technology and the market has been established for a long time.

Household waste is bought by waste incineration facilities, where it is in most cases burnt to become district heating and sometimes also co-produced electricity. Since not all municipalities have their own waste incineration facility there is a considerable waste trade, although here it is the receiver who is paid for accepting the waste. It is less expensive than landfilling. For instance the energy plant in Uppsala is presently receiving waste from more than 25 municipalities in the region.

An international trade in waste is also developing, for e.g. paper, scrap iron and waste. In Sweden the waste demand is bigger than the supply. Greenpeace estimates that the amount of waste imported to Sweden is 200,000-300,000 tonnes per year (2001), coming from e.g. Finland, Germany, and Norway.

Outlook
Box 18.7

The international hazardous waste market

From an environmental perspective import of waste is negative in many ways. Above all because it makes problems with consumption and waste in the exporting country invisible. Export of waste is a way of ignoring the problem and not finding sustainable solutions for handling the waste.

Hazardous waste trade follows a path of least economic and political resistance. In the 1980s and early 1990s Greenpeace documented many cases of rich industrialised countries dumping hazardous waste on poor developing countries. These countries had poor environmental and occupational health standards and hence provided a cheap way to solve the waste problem of the first world.

In 1989 an international convention banning hazardous waste trade from rich (OECD) to poor (non-OECD) countries was finally signed (Basel Convention on the Transboundary Movement of Hazardous Waste).

While the Basel convention has helped curb the most insidious forms of waste trade, the problem of rich countries' export to poor ones has not been fully eliminated. One alarming problem among many is the issue of ship breaking. To maximise profits, ship owners send their vessels to the scrap yards of India, China, Pakistan, Bangladesh, the Philippines, and Vietnam where health and safety standards are virtually non-existent and workers are desperate for jobs. The ships often contains many dangerous materials. Well over 100,000 workers are estimated to be employed at ship breaking yards worldwide.

One example is from 1999 when Greenpeace investigated a ship breaking yard in Jiangyin, near Shanghai and observed dangerous and irresponsible handling procedures for ship parts with insulation material of asbestos-like fiber structures. Greenpeace tested ash samples from the cutting area and found high levels of arsenic, lead, cadmium, and chromium - pollutants that can disperse and accumulate in the yard, in the nearby rice fields, and possibly reach the residential areas and the Yangtze River.

Emma Öberg, Greenpeace

technologies for combustion of municipal and hazardous waste. This concerns the charging system, oven type, incineration temperature, and the volume and composition of residues. Thanks to technological development the combustion process may be designed according to waste to be burned making it efficient, effective and producing the lowest possible amount of pollutants.

The incineration of waste leads approximately to 70% weight reduction and 80-90% volume reduction. Toxic or hazardous substances are concentrated into two streams of ashes which are easier to handle and control than the original waste. Recovered scrap can be used by melting industries. Bottom and fly ashes can be applied to layer roads and sites, to build sound-suppressing walls or artificial ski hills or to replace adding material for concrete, but gas cleaning residues have to be treated as hazardous waste and put safely into the landfill.

Most of combustion facilities generate energy which can be used for production of electricity, heating, or distilled water. Production of energy is often the reason today for incineration (waste-to-energy plants). In Norway 70% of municipal waste burned is used for energy generation.

The key environmental problems connected with waste incineration is contamination of the flue gas. This mainly contains dust, heavy metals, products of incomplete combustion such as chlorine containing dioxines and dibenzofurans, and acidifying gases, as SO_x and NO_x. The cleaning equipment captures a great deal of pollutants. However not all of them can be removed from flue gases.

In the Baltic Sea region waste incineration is commonly used in Germany and in the Scandinavian countries. In the countries on the southern and eastern part of the Baltic Sea the use of waste incineration is increasing.

Landfill

A landfill is an organised dumping on land. Properly managed landfill sites are a very effective means of solid waste disposal, both for municipal and industrial waste. The principle is simple: the waste is put on or in the ground and covered by soil. Organised dumping has to meet the following requirements in order to avoid future environmental contamination and human exposure to toxic substances:

Figure 18.17. Recycling of tires. Burning of tires gives rise to large amounts of toxic chemicals. Today tires can be ground and reused in several ways. (Photo: Inga-May Lehman Nådin.)

1. Landfills should be sited on high ground, well above the water table.
2. The floor has to prevent leachate from entering the groundwater by channelling it and to a special leachate-collection system. If necessary, the leachate will then be treated. In order to fulfil these requirements the floor is built as follows:
   - contoured so that water will drain into a tile leachate-collection system,
   - covered by a layer of impervious clay or plastic liner or both, and
   - covered by a layer of coarse gravel and a layer of porous earth.
3. The infiltration of rain water has to be minimal in order to prevent production or lecheate. This may be done by shaping of the landfill. The layers of refuse are positioned such that the fill is built up in the shape of a pyramid with a cap of top soil and then seeded.
4. The site should be divided into a number of areas (cells) into which waste of known characteristics are placed to avoid complications for future removal of waste for recycling or further treatment.
5. The entire site should be surrounded by a series of groundwater-monitoring wells enabling environmental control of the landfill both during and after its operation.

Landfill, carefully managed, is still seen as a highly appropriate means of disposal for much hazardous waste. However, the above requirements have to be modified in order to fit the special conditions required for storage of each particular waste. E.g., the main object for a secure storage of solid waste from coal combustion and coal desulphurisation is to properly cover the landfill to prevent the production of leachate.

In many cases the hazardous waste has to be immobilised before disposition (incorporation into a solid matrix, stabilisation or incapsulation within an impermeable polymeric cover).

As shown above, solid waste is mainly disposed of on land either directly or after being transformed, i.e. ashes. Its impact on the environment is mainly connected with the leaching of contaminants from the dumping places. The contamination of the environment will depend both on the waste composition (e.g. contamination by heavy metals) and the quality of the landfill or deposition place. The main environmental problems connected with landfilling are:

- Leachate generation and groundwater contamination.
- Methane production (in the case of municipal waste) because of anaerobic degradation. If the waste contain organic matter (which is the case of municipal waste) the anaerobic decomposition process will start 3-10 years after closing the landfill. Biogas is one of the major by-products. It consists of methane, hydrogen and carbon dioxide. The gas is highly explosive, however the controlled removal of it reduces the danger of explosion.

- Incomplete decomposition. There are materials which are resistant to natural decomposition, e.g. plastics. Research has shown that under certain conditions (e.g. moisture content) even highly degradable materials are decomposed very slowly (e.g. in a 30 years old landfill newspapers were recovered in readable state).
- Settling as a consequence of waste decomposition.
- Erosion in the case of industrial, unprotected waste heaps.

Hazardous waste

The definition of hazardous waste varies from country to country which makes a comparison of waste produced very difficult. The definition of hazardous waste is often parallel to that of municipal and industrial, because refuse from these categories may also be hazardous.

Hazardous waste is here defined as a refuse that when released in relatively small amounts is capable of producing severe and long-lasting damage to human health or the environment (Jackson & Jackson, 1996). In the context of solid waste, the hazardous fraction includes all radioactive waste (even ashes from fossil fuel combustion with radioactivity higher than permissible), waste contaminated with bacteria (medical waste), or toxic waste (e.g. phospho-gypsum waste from chemical industry). Lists over hazardous waste are prepared by environmental ministries in every country.

In most countries there are special centres for the handling of hazardous waste. These have expertise to either store the waste or destroy it, mostly by incineration. In Sweden, such a hazardous waste centre has been established in a former oilshale industry south of Örebro. In Latvia, a former military base was rebuild to safely store old remains of pesticides.

All organic substances may in principle be safely incinerated and converted to carbon dioxide and water, even if high temperatures may be required. It is however important to manage the residues correctly to avoid emission of toxic gases, etc.

A special case is the destruction of nerve gases under the international convention banning chemical warfare. Although this task is extremely dangerous it illustrates that the hazardous waste problem is manageable with modern techniques.

Figure 18.18. Hazardous waste. Light-tubes contain considerable amounts of mercury. They are collected separately and sent to special companies with equipment to recover the mercury. (Photo: Lars Rydén.)

Nuclear waste

Nuclear waste is foremost waste produced in the nuclear power generation industry, and includes waste from all stages of uranium mining and processing. In addition, radioactive waste is produced in e.g. medical, research and industrial activities using radioactive isotopes (GUS, 1997). Also the mining industry contributes to nuclear waste generation as excavated minerals are contaminated by radionuclides (SOU, 1998).

Depending on the level of radioactivity and point of production in the nuclear fuel chain, nuclear waste may be classified as low, medium, or high-level waste. High-level waste is the radioactive waste generated by the reprocessing of spent fuel, and presents dangers similar to spent fuel (reactor fuel after it has been used in a nuclear reactor). Once a nuclear reactor is no longer operating, the reactor buildings themselves are low and medium level waste.

Radioactive waste has special characteristics. Its danger to human health and the environment depends on the radioactive decay, i.e. when an unstable isotope releases particles and rays to change into another radioisotpe and eventually become stable and cease to be radioactive. The rate of radioactive decay is expressed in half-life, i.e. the time for half an amount of a radioactive isotope to decay. As long as radioactive materials are kept isolated from life forms, the decay proceeds harmlessly. Most nuclear power stations use uranium for fuel. Uranium fission results in a heterogeneous mixture of radionuclides with a wide range of half-lives, e.g. 2.8 days for molybdeum-99 and 24,000 years for plutonium-239 (Nobel

& Wright, 1996). It thus takes several hundred-thousand years before spent fuel is harmless to life forms from a radioactive perspective.

Although there are uranium deposits in Russia, Sweden, Finland and Germany, other than in Russia, all of the uranium for nuclear fuel in the Baltic Sea region is imported (Morović & Tuschy, 1997).

Nuclear waste disposal is a special case of long term solid waste *final disposal*. Spent fuel is most often stored on sites of power plants in special deep swimming-pool-like tanks. After a few years of decay the waste can be handled more easily and safely, but still has to be isolated from the environment for several hundred-thousand years. Some countries, e.g. Sweden, have established an intermediate storage facility to be used until a longterm solution has been established. However, at present there is no known longterm solution.

A widely disputed concept proposed by the nuclear industry in some countries, including Sweden and Finland, is to solidify the spent fuel in glass, put it in sealed copper containers and deposit the containers in deep, stable rock formations. The location of such a facility is highly problematic, since many people are concerned about the local consequences.

Final disposal

The philosophy and methodology of final disposal of material which is not changing or changing extremely slowly is not only a problem for nuclear waste. The difficulties connected with final disposal of stable materials apply also to future management of toxic heavy metals.

In Sweden, the parliament decided 1992 that several heavy metals are to be phased out from use in society, including lead, mercury, and cadmium (Se chapter 12). These materials are now collected and will have to be disposed of in longterm safe storage places. The collection and storage of mercury is well underway. Lead will most likely be used for a long time, e.g. in car batteries, and management of lead will in this case be based on reuse and a well functioning and controlled technical use-reuse system.

Review questions

1. Describe the various kinds of soils in the region and their composition, how common they are and where they are found, and name the dominating kinds of soils where you live.
2. Review the different functions of soil.
3. List the most important threats to soil.
4. Describe the situations in which soil is contaminated due to improper waste management.
5. Describe six in-site methods for remediation of contaminated soils.
6. Which are the hierarchy of solid waste management activities according to the EU waste directive?
7. What are the pros and cons of depositing contaminated soil in landfills?
8. Describe the ways to improve solid waste management that avoids linear flows and thus relies on recycling. How is recycling organised where you live?
9. Describe the methods of incineration of solid waste, including hazardous waste, and its pros and cons.
10. What are the methods for final disposal of solid waste and when are they used?

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Internet resources

European Topic Centre on Waste and Material Flows
http://waste.eionet.eu.int/

FAO information on desertification
http://www.fao.org/desertification/intro.asp?lang=en

Greenpeace Sweden - Waste incineration
http://www.greenpeace.org/majordomo/mhonarc-test/msg00691.html

IAEA - International Atom Energy Agency
http://www.iaea.org/worldatom/

The Soil Science Society of America
http://www.soils.org/

Swedish EPA - Acidification of Forest Land
http://www.internat.environ.se/index.php3?main=/documents/legal/assess/assedoc/forstdoc/soilacid.htm

Swedish nuclear fuel and waste management company (SKB)
http://www.skb.se/english/

United Nations Secretariat on the Convention to Combat Desertification
http://www.unccd.int/main.php

USDA World Soil Resources
http://www.nhq.nrcs.usda.gov/WSR/

US EPA - Office of Solid Waste
http://www.epa.gov/epaoswer/osw/index.htm

World Information Service on Energy (WISE)
http://www.antenna.nl/wise

World Resource Center - Materials Ecology
http://www.wri.org/matecology/

Glossary

acidification
lowering pH value of a soil with low buffering capacity, typically forest soil, due to acid rain

biopiles
spreading of contaminated soils on a lined treatment bed, where air and/or nutrients dissolved in water are flushed through the soil pile to optimise biodegradation of contaminants

bioremediation
a method using micro-organisms to treat contaminated soils to transform hazardous chemicals to less toxic or non-toxic compounds; bioremediation processes for excavated contaminated soils include biopiles, landfarming, composting and use of slurry reactors

bioventing
ventilation of a contaminated soil by pulling a vacuum to enhance aerobic biodegradation of contaminants, or air sparging which volatilize contaminants in the saturated zone and enhance aerobic biodegradation

brownfield sites
places with contaminated soils damaged by pollution due to e.g. industrial activities and the infrastructure it supports

chemical and physical on-site treatment
technologies to deal with contaminated soil on-site including heating, i.e. thermal process, soil washing or chemical extraction, soil flushing, solidification/stabilization, and chemical destruction

composting
microbiological degradation of organic waste, often in special containers, used to treat municipal solid waste, wastewater treatment sludge, to leave behind a soil like residue, the compost to be used for soil improvement and fertilisation

construction industry waste
refuse generated by the construction industry, including all solid materials used for construction of buildings, such as wood, various types of bricks, insulating materials, hollow bricks, glass, plastics, and metals

contaminated soils
soils damaged by pollution due to e.g. deposit of waste, industrial activities, military activities, and the infrastructure it supports, including metallurgic factories, petrochemical industries factories for paints or pharmaceutics, petrol stations, car washing stations and landfills

desertification
soil impoverishment through loss of organic material, e.g. by erosion, harvest, repeated burning, and mineralisation, in the extreme leading to desert formation

drainage
reducing water content in over-moist soils and meadow soils to allow agriculture

ecological rucksack
material by-flows which are unavoidable and connected to extraction of useful materials but are not incorporated in the extraction product, such as overburden from mining in form of rock, a major category of solid waste

energy generation waste
solid waste from fossil fuel combustion include residual solids, i.e. ashes, furnace bottom ash and pulverised fuel ashes and products from fuel desulphurisation, depending on both the quality of fuel used and the combustion technology

erosion
loss of soil, transported away either by wind and water, may be the single largest threat against the future productivity of the Earth

final disposal
disposal of material which is not changing or changing extremely slowly, that is toxic metals and nuclear waste, consisting of containment in capsules, incapsulation, and storage far under surface in old mines or newly constructed mountain halls

ground water remediation
activities to decontaminate a soil which pollutes ground water, through *ground water pumping* to remove the pollutant, the traditional method, which may require pumping water for years or decades; *soil vapor extraction*, which removes contaminants from the unsaturated soil zone by pulling a vacuum; and *bioventing* or *air sparging* to enhance aerobic biodegradation of contaminants

hazardous waste
waste, when released in relatively small amounts, that is capable of producing severe and long-lasting damage to human health or the environment; the definition of hazardous waste used in legal regulations varies from country to country often parallel to that of municipal and industrial, because refuse from these categories may also be hazardous

incapsulation
immobilisation of hazardous waste before disposition, including stabilisation by incorporation into a solid matrix within an impermeable polymeric cover

incineration
burning of waste in combustion facilities at temperature 800-1,400 ^{o}C or more, in which hazardous wastes are completely destroyed because of high temperature and long retention time, applied to both municipal and organic industrial hazardous waste

industrial solid waste
solid waste form industry in particular, mining and quarrying waste, energy generation waste and construction industry waste

land reclamation
improvement of land by protection and improvement of soil, e.g. by plantation to bind soil and reduce erosion, increase organic content in soil and balance water content

landfarming
spreading of contaminated soils on the surface of the ground to enhance natural microbial degradation of contaminants in the soil often successful in treating petroleum refinery waste in areas where air emissions do not pose unacceptable levels of health risks

landfill
an organised dumping of waste on land, as an effective means of solid waste disposal, both for municipal and industrial waste, where the waste is put on or in the ground and covered by earth

leaching
transfer of contaminants with water from the dumping places leading to groundwater contamination; the main environmental problem connected to landfilling

mineral soils
soils with less than 10% of organic matter, the most common soil type

Glossary

mining and quarrying waste
accounting for the largest amounts of solid waste, about 70% in the region, consisting of refuse from mining metal ores, hard coal, lignite, oil-shale and peat

municipal waste
includes commercial waste and waste generated by households, with typical fractions common for all countries, although proportion depends on the source (commercial versus residential), the time of the year, as well as packaging consumption

natural recycling
recycling using natural cycles including e.g. composting where organic material is returned to the soil, or use of sludge from waste water treatment plants to fertilize fields

nuclear waste
radioactive waste produced by the nuclear industry, including waste from all stages of uranium mining and processing, as well as radioactive waste produced in e.g. medical, research and industrial activities using radioactive isotopes

on-site containment
prevention of migration of contaminants from contaminated soil to groundwater, surface water or other sensitive receptors through the construction of impermeable barriers, such as grout curtains, slurry walls and sheet-piling cut-off walls, or diversion of surface and ground water from the contaminant source area

organic soils
soil with a mixture of partially degraded plant and animal material and matter produced by microorganisms, allowing agriculture and other types of bioproduction: most soils have less than 10% organic matter, they are so-called mineral soils

phytoremediation
method using plants to remediate inorganic or organic contaminants at the root zone in soils, to achieve soil stabilisation, minimisation of contaminant leaching and aesthetic improvement at low capital costs, often efficient for heavy metal removal

reuse and recycling
includes collection of valuable fractions of refuse which can be later used as such or as raw material for manufacturing of new products

salination
increased salt content in a soil, following e.g. extensive irrigation, which reduces the fertility of the soil and in the end turns it into desert

slurry reactors
treatment of contaminated soil with nutrient-rich water in bioreactor vessels or lined lagoons to form an aqueous slurry where biodegradation occurs

soil components
parts of soil, namely inorganic matter, organic matter, soil water (groundwater), and soil atmosphere, in a mixture; different soil types have very different amounts of these four components

soil heating
commonly used thermal process for the treatment of soil with organic wastes, through heating to temperatures as high as 650 ^{o}C to achieve desorption of the organic waste from the soil matrix

soil protection
legal protection of soil *quantity*, regulated by the acts dealing with regional planning and protection of landscape, forest, pastures, farmlands or wetlands, and soil *quality* needed to protect drinking water and the quality of food produced on the soil

soil remediation
activities to remove or reduce the pollution in soil to eliminate exposure of humans and other living organisms to the contaminants and eliminate the source of contamination to ground water; remediation of contaminated soils is normally a difficult and expensive operation; remediation activities include the *removal* of the contaminated material through excavation or dredging and its safe off-site disposal, and *on-site treatment* such as destruction or containment

soil washing
also called chemical extraction and soil flushing, methods in which chemicals are directly injected in the ground to remove the contaminants

solid waste
any movable material that is perceived to be of no further use and that is permanently discarded; the material defined as waste depends on the management system and thus the amount of waste is often decreases as waste management develops

stabilization
also called solidification, treatment of contaminated soil to contain contaminants and minimize their release to the environment

technical recycling
return, renovation and reuse of non-renewable materials, especially some metals, e.g. return of lead batteries from cars to be renovated and reused; in the case of toxic material such as lead the technical cycle need to be very efficient to avoid an unwanted environmental impact

waste collection
separate collection of different waste fractions as a first step towards good waste management; municipalities are obliged to organise waste collection from households

waste management
strategies and methods to reuse, recycle or get rid of refuse; today a main goal is to treat waste in a way which could save as much resources as possible, to avoid loss of natural resources, and see that waste is right resources in the wrong place

waste management recommendation of the EU
a method of handling waste based on a hierarchy of waste treatment methods: waste minimisation, waste prevention, reuse, recycling, recovery for energy, and finally deposition