Contaminated land and Bioremediation

- **Contaminated land** is another example of a widely appreciated, yet often poorly understood environmental problem
- The importance of land remediation in cleaning up the residual effects of previous human activities on a site lies in two spheres.

Firstly,

Throughout the world, environmental legislation is becoming increasingly stringent and the tightening up of the entire regulatory framework has led to both a real drive for compliance and a much greater awareness of liability issues within industry.

Secondly,

As the pressure grows to redevelop old, unused or derelict so called ‘brown-field’ sites, rather than develop previously untouched ‘green-field’,

the need to remove any legacy of previous occupation is clear.

- A number of technologies are available to achieve such a clean-up, of which bioremediation, in its many individual forms, is only one.

- The idea of ‘contaminated land’ is something which is readily understood, yet, like pollution somewhat more difficult to define absolutely.
- Implicit is the presence of substances which, when present in sufficient quantity or concentration,are likely to cause harm to the environment or human health.
- Many kinds of sites may give rise to possible contamination concerns, such as asbestos works,chemical works, garages and service stations, gas works, incinerators, iron and steel works, metal fabrication shops, paper mills, tanneries, textile plants, timber treatment plants, railway yards and waste disposal sites.
- land remediation continues to grow in importance because of pressures on industry and developers.
- The motive force is, then, a largely commercial one and, consequently, this imposes its own set of conditions and constraints. Much of environmental biotechnology centres on the ‘unwanted’ aspects of human activity and the clean-up of contaminated land is no exception to this general trend.
- As such, it is motivated by necessity and remedies are normally sought only when and where there is unacceptable risk to human health,the environment and occasionally to other vulnerable targets.

- In broad terms it is possible to view the driving forces on remediation as characterised by a need to limit present or future liability, increase a site's value, ease the way for a sale or transfer, comply with legislative, licensing or planning requirements,or to bolster corporate image or public relations.
- Generally, one or more of these have to be present before remediation happens.
- Having established the need for treatment, the actual remedies to be employed will be based on a realistic set of priorities and will be related to the risk posed.
- This, of course, will require adequate investigation and risk assessment to determine.
- It should be apparent, then, from the preceding discussion that the economics of remediation and the effective use of resources are key factors in the whole contaminated land issue.
- Hence, in purely economic terms, remediation will only take place when one or more of the driving forces becomes sufficiently compelling to make it unavoidable.
- It will also tend towards the minimum acceptable standard necessary to achieve the required clean-up.

- The choice of method and the determination of the final remediation standard will always be chiefly governed by site-specific factors including intended use, local conditions and sensitivities, potential risk and available timeframe.

Remediation Methods:

The currently available processes for soil remediation can be divided into five generalised categories:

- biological;
- chemical;
- physical;
- solidification/vitrification;
- thermal.

Biological:

Biological methods involve the transformation or mineralisation of contaminants to less toxic, more mobile, or more toxic but less mobile, forms. This can include fixation or accumulation in harvestable biomass crops.

- The main advantages of these methods are their ability to destroy a wide range of organic compounds, their potential benefit to soil structure and fertility and their generally nontoxic, ‘green’ image.
- On the other hand, the process end-point can be uncertain and difficult to gauge, the treatment itself may be slow and not all contaminants are conducive to treatment by biological means.

Chemical:

- Toxic compounds are destroyed, fixed or neutralised by chemical reaction.
- The principal advantages are that under this approach, the destruction of biologically recalcitrant chemicals is possible and toxic substances can be chemicallyconverted to either more or less biologically available ones, whichever is required.
- On the downside, it is possible for contaminants to be incompletely treated, the reagents necessary may themselves cause damage to the soil and often there is a need for some form of additional secondary treatment.

Physical:

- This involves the physical removal of contaminated materials, often by concentration and excavation, for further treatment or disposal.
- As such, it is not truly remediation, though the net result is still effectively a clean-up of the affectedsite.
- Landfill tax and escalating costs of special waste disposal have made remediation an increasingly cost-effective option, reversing earlier trends which tended to favour this method.
- The fact that it is purely physical with no reagent addition may be viewed as an advantage for some applications and the concentration of contaminants significantly reduces the risk of secondary contamination.
- However,the contaminants are not destroyed, the concentration achieved inevitably requires containment measures and further treatment of some kind is typically required.

Solidification/vitrification:

- Solidification is the encapsulation of contaminants within a monolithic solid of high structural integrity, with or without associated chemical fixation, when it is then termed ‘stabilisation’.
- Vitrification uses high temperatures to fuse contaminated materials.
- One major advantage is that toxic elements and/or compounds which cannot be destroyed, are rendered unavailable to the environment.
- As a secondary benefit,solidified soils can stabilise sites for future construction work.
- Nevertheless, the contaminants are not actually destroyed and the soil structure is irrevocably damaged.
- Moreover, significant amounts of reagents are required and it is generally not suitable for organic contaminants.

Thermal:

Contaminants are destroyed by a heat treatment, using incineration, gasification, pyrolysis or volatisation processes.

Clearly, the principal advantage of this approach is that the contaminants are most effectively destroyed.

- On the negative side, however, this is achieved at typically very high energy cost, and the approach is unsuitable for most toxic elements, not least because of the strong potential for the generation of new pollutants.
- In addition, soil organic matter,and, thus, at least some of the soil structure itself, is destroyed.

In Situ and Ex Situ Techniques:

- A common way in which all forms of remediation are often characterised is as in situ or ex situ approaches.
- These represent largely artificial classes, based on no more than where the treatment takes place – on the site or off it –
- But since the techniques within each do share certain fundamental operational similarities, the classification has some merit.

In situ

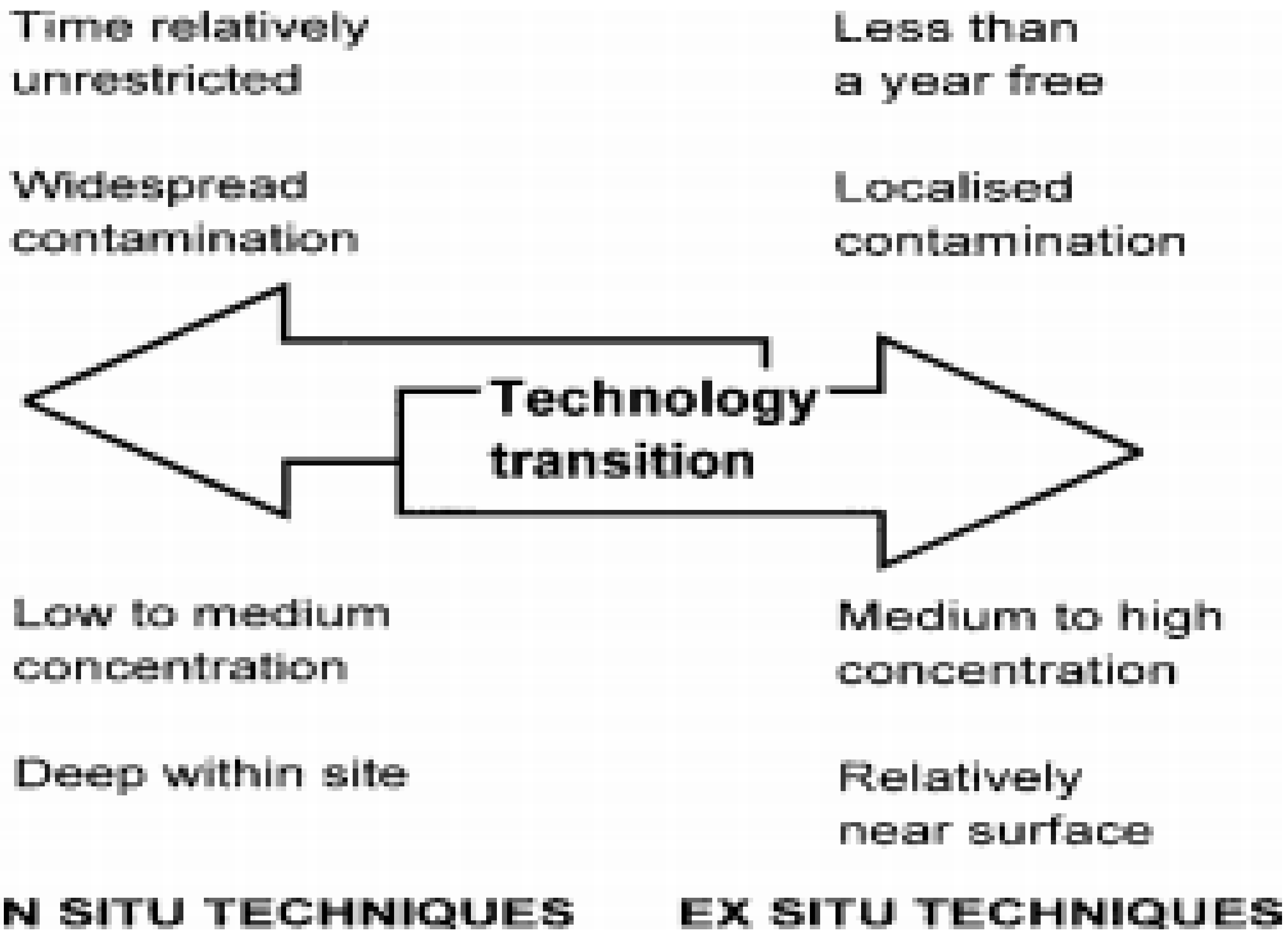
- The major benefit of approaches which leave the soil where it is for treatment, is the low site disturbance that this represents, which enables existing buildings and features to remain undisturbed, in many cases.
- They also avoid many of the potential delays with methods requiring excavation and removal, while additionally reducing the risk of spreading contamination and the likelihood of exposing workers to volatiles.
- Generally speaking, in situ methods are suited to instances where the contamination is widespread throughout, and often at some depth within, a site, and of low to medium concentration.
- Additionally, since they are relatively slow to act, they are of most use when the available time for treatment is not restricted.
- These methods are not, however, without their disadvantages and chief amongst them is the stringent requirement for thorough site investigation and survey,almost invariably demanding a high level of resources by way of both desktop and intrusive methods.
- In addition, since reaction conditions are not readily controlled,the supposed process ‘optimisation’ may, in practice, be less than optimum and the true end-point may be difficult to determine.
- Finally, it is inescapable that all site monitoring has an in-built time lag and is heavily protocol dependent.

Ex situ

- The main characteristic of ex situ methods is that the soil is removed from whereit originally lay, for treatment.
- Strictly speaking this description applies whether the material is taken to another venue for clean-up, or simply to another part of the same site.
- The main benefits are that the conditions are more readily optimised, process control is easier to maintain and monitoring is more accurateand simpler to achieve.
- In addition, the introduction of specialist organisms, on those occasions when they may be required, is easier and/or safer and generallythese approaches tend to be faster than corresponding in situ techniques.
- They are best suited to instances of relatively localised pollution within a site, typically in ‘hot-spots’ of medium to relatively high concentration which are fairly near to the surface.
- Amongst the main disadvantages are the additional transport costs and the

inevitably increased likelihood of spillage, or potential secondary pollution, represented by such movement.

- Obviously these approaches require a supplementary area of land for treatment and hence they are typically more expensive options.



Technology transition

N SITU TECHNIQUES	EX SITU TECHNIQUES
Time relatively unrestricted	Less than a year free
Widespread contamination	Localised contamination
Low to medium concentration	Medium to high concentration
Deep within site	Relatively near surface

ors affecting technology suitability

Intensive and Extensive Technologies:

- **Intensive technologies** can be characterised as sophisticated, fast-acting, highintervention strategies, with a heavy demand for resources and high initiation,running and support costs.
- Their key factors are a fast response and low treatment time, which makes them excellent for heavy contamination conditions, since they

can make an immediate lessening in pollutant impact.

- Soil washing and thermal treatments are good examples of 'intensive' approaches.

Extensive methods are lower-level interventions, typically slower acting,based

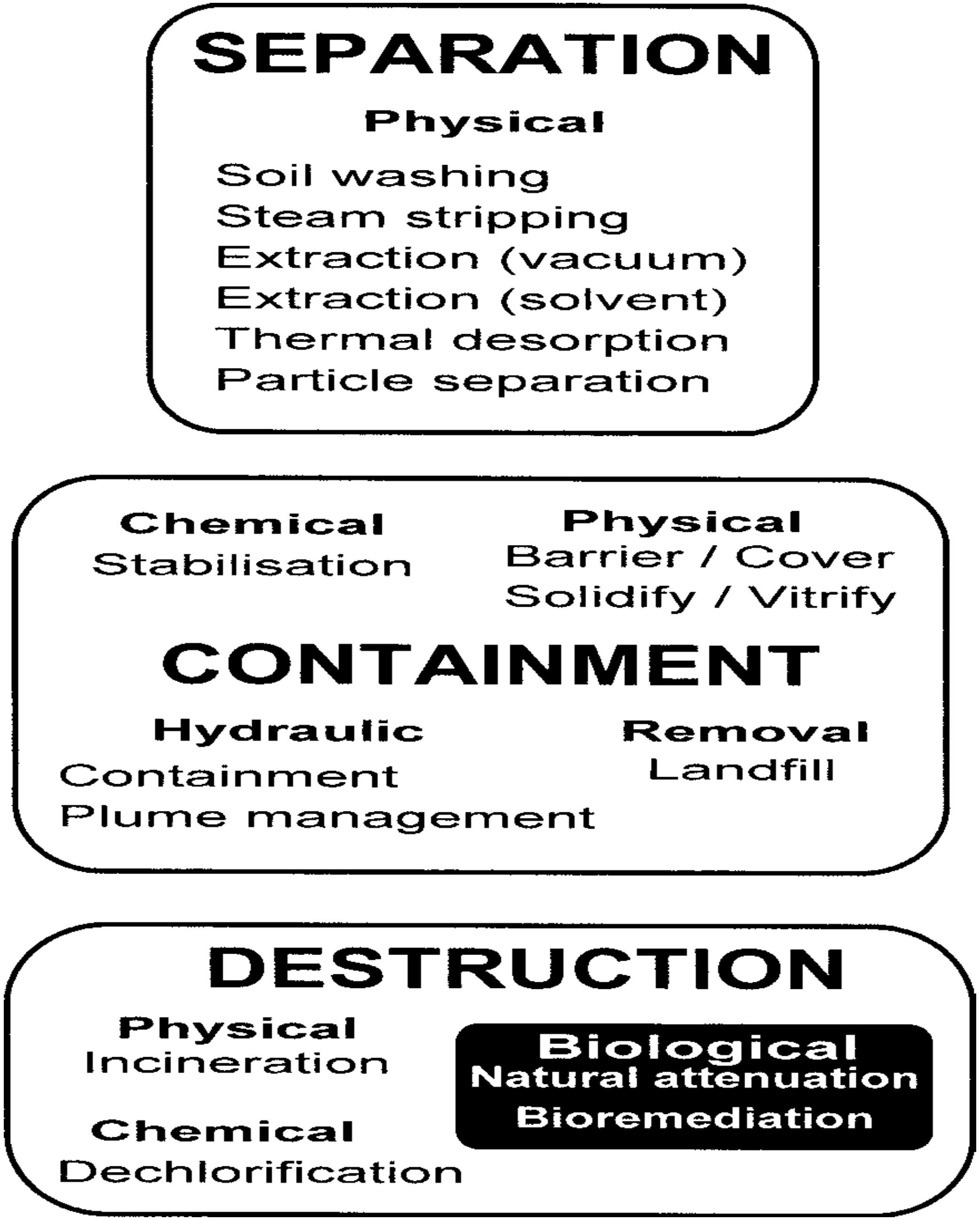
on simpler technology and less sophisticated engineering, with a smaller resource requirement and lower initiation, running and support costs.

These technologies have a slower response and a higher treatment time, but their lower costs make wider application possible, particularly since extensive land remediation treatments do less damage to soil quality.

Accordingly, they are well suited to large-scale treatment where speed is not of the essence.

Examples include composting, the promotion of biological activity in situ within the root-zone,precipitation of metal sulphides under anaerobic conditions and the cropping of heavy metal accumulator plants.

- All these systems of classification are at best generalisations, and each can be useful at different times, dependent on the purpose of the consideration.
- They are merely a convenient way of looking at the available techniques and should not be regarded as anything more than a helpful guide.
- As a final aspect of this, it is possible to examine the various forms of land remediation technologies in terms of their overall functional principle.
- Hence, the approaches may be categorised as ‘destructive’, ‘separating’ or ‘containing’, dependent on their fundamental mode of operation
- The principal attraction of this systemisation is that it is defined on the basis of representing the fate of the pollutant.



SEPARATION

Physical
Soil washing
Steam stripping
Extraction (vacuum)
Extraction (solvent)
Thermal desorption
Particle separation

Chemical
Stabilisation

Physical
Barrier / Cover
Solidify / Vitrify

CONTAINMENT

Hydraulic
Containment
Plume management

Removal
Landfill

DESTRUCTION

Physical
Incineration

Chemical
Dechlorification

Biological
Natural attenuation
Bioremediation

Technology classification

Suitability of Bioremediation

- Bioremediation as a biotechnological intervention for cleaning up the residual effects of previous human activities on a site, typically relies on the inherent abilities and characteristics of indigenous bacteria, fungi or plant species.
- The emphasis will concentrate on the contribution made by the first two types of organism.
- The use of plants, including bioaccumulation, phytoextraction, phytostabilisation and rhizofiltration, all of which are sometimes

  collectively known as **phytoremediation.**
- Thus, the biological mechanisms underlying the relevant processes are biosorption, demethylation, methylation, metal-organic complexation or chelation, ligand degradation or oxidation.
- Microbes capable of utilising a variety of carbon sourcesand degrading a number of typical contaminants, to a greater or lesser extent,are commonly found in soils.
- Optimising conditions for them, they can be encouraged to do what they do naturally, but more swiftly and/or efficiently.
- This is the basis of the majority of bioremediation and proceeds by means of one of the three following general routes.

Mineralisation, in which the contaminant is taken up by microbe species, used as a food source and metabolised, thereby being removed and destroyed.

Incomplete, or staged, decomposition is also possible, resulting in the generation and possible accumulation of intermediate byproducts, which may themselves be further treated by other micro-organisms.

Cometabolism, in which the contaminant is again taken up by microbes but this time is not used as food, being metabolised alongside the organism's food into a less hazardous chemical. Subsequently, this may in turn be mineralised by other microbial species.

Immobilisation, which refers to the removal of contaminants, typically metals, by means of adsorption or bioaccumulation by various micro-organism or plant species.

Bioremediation is most suited to organic chemicals, but it can also be effective in the treatment of certain inorganic substances and some unexpected ones at that. Metals and radionuclides are good examples of this.

Though, obviously, not directly biodegradable themselves, under certain circumstances their speciation can be changed which may ultimately lead to their becoming either more mobile and accessible or less so.

The net result produced in either case can, under the right conditions, be a very effective functional remediation.

- A list of typical contaminants suitable for bioremediation would include the likes of crude oil and its derivatives, some varieties of fungicides and herbicides, hydrocarbons, glycols, phenols, surfactants and even explosives

Factors Affecting the use of Bioremediation:

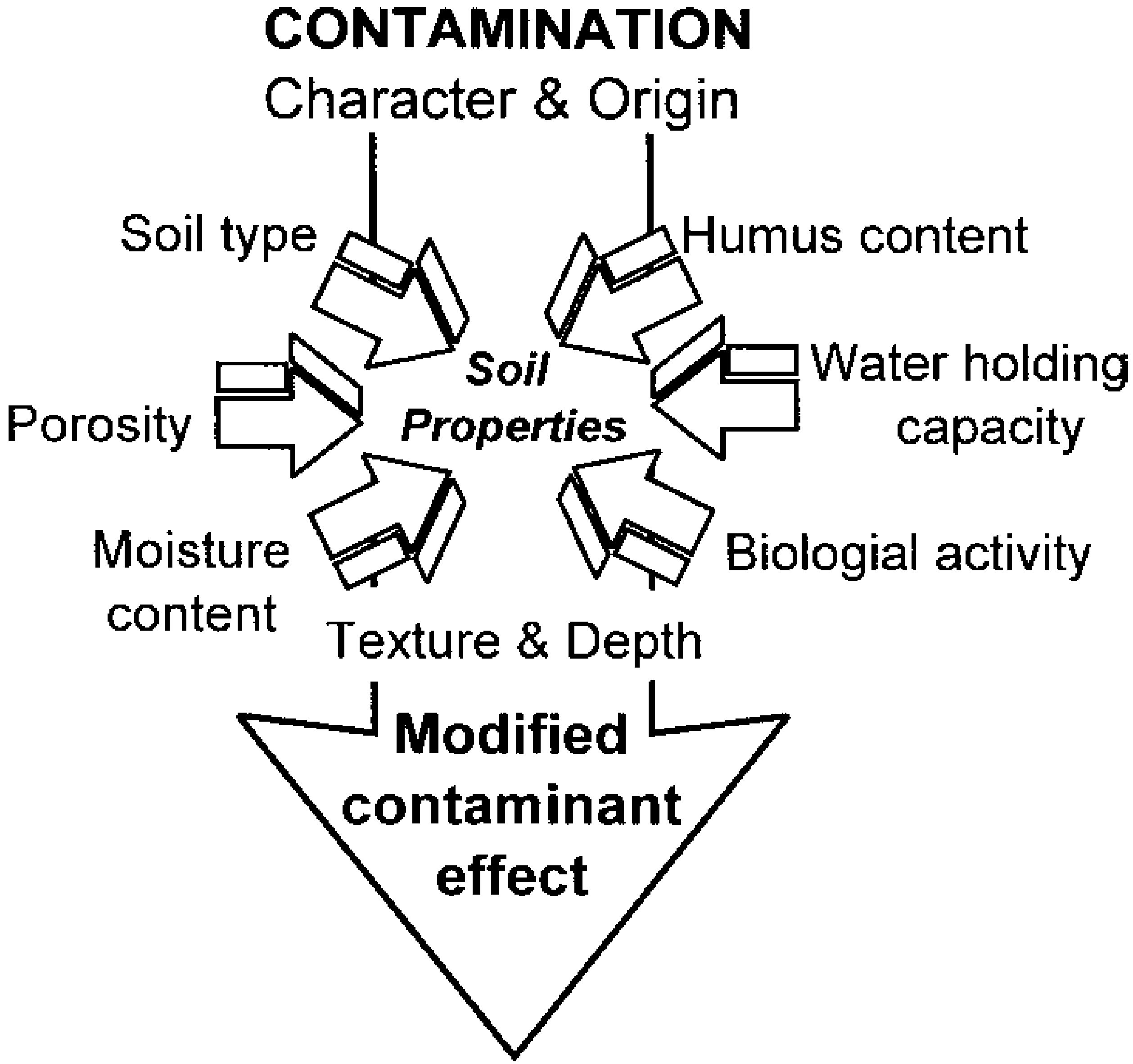
It is possible to divide these into **two** broad groups; those which relate to the character of the contamination itself and those which depend on environmental conditions.

- The former encompass both the chemical nature of the pollutants and the physical state in which they are found in a given incident.
- Thus, in order for a given substance to be open to bioremediation, clearly it must be both susceptible to, and readily available for, biological decomposition. Generally it must also be dissolved, or at the very least, in contact with soil water and typ ically of a low–medium toxicity range.
- The pinciple environmental factors of significance are temperature, pH and soil type.bioremediation tends to rely on the natural abilities of indigenous soil organisms and so treatment can occur between 0–50 ◦C, since these temperatures will be tolerated.

- However, for greatest efficiency, the ideal range is around 20–30 ◦C, as this tends to optimise enzyme activity.

- In much the same way, a pH of 6.5–7.5 would be seen as optimum, though ranges of 5.0–9.0 may be acceptable, dependent on the individual species involved.
- Generally speaking, sands and gravels are the most suitable soil types for bioremediation, while heavy clays and those with a high organic content, like peaty soils, are less well indicated.
- However, this is not an absolute restriction, particularly since developments in bioremediation techniques have removed the one-time industry maxim that clay soils were impossible to treat biologically.
- It should be apparent that these are by no means the only aspects which influence the use of remediation biotechnologies.
- Dependent on the circumstances; nutrient availability, oxygenation and the presence of other inhibitory contaminants can all play an important role in determining the suitability of bioremediation, but these are more specific to the individual application.
- The areas of relevance are the likes of the site character, whether it is contained or if the groundwater runs off, what contaminants are present, where they are, in what concentrations and whether they are biodegradable.

- Clearly then, there are benefits to the biological approach in terms of sustainability, contaminant removal or destruction and the fact that it is possible to treat large areas with low impact or disturbance.
- However, it is not without its limitations. For one thing, compared with other technologies, bioremediation is often relatively slower, especially in situ, it is not equally suitable for all soils.
- .Indeed, soil properties may often be the largest single influence, in practical terms, on the overall functional character of pollution, since they are major factors in modifying the empirical contamination effect.
- The primary influence consists of the contaminants themselves and actual origin of the contamination, which clearly have a major bearing on the overall picture
- . However, edaphic factors such as the soil type, depth, porosity, texture, moisture content, water-holding capacity, humus content and biological activity may all interact with the primary influences, and/or with each other, to modify the contamination effect, for better or worse


CONTAMINATION
Character & Origin
Soil type
Humus content
Porosity
Soil Properties
Water holding capacity
Moisture content
Biologial activity
Texture & Depth
Modified contaminant effect

Biotechnology Selection

- Although the primary focus of remediation methods commonly falls on technologies dependent on a relatively high engineering component, there is one purely biological treatment option which can be a very effective means of clean-up Known variously as **'natural attenuation',** '**passive remediation', 'bioattenuation'** or **'intrinsic remediation'**,
- It is appropriate for sites where the contamination does not currently represent a clear danger to human health or the environment.
- Thoughtit is not an engineered solution, neither is it a 'do nothing' approach as is sometimes stated, since it is not an exercise in ignoring the problem, but reasoned decision on the basis of the necessary site investigations, to allow nature to take its course.
- The approach works with natural cycles and the pre-existing indigenous microbial community to bring about the required treatment.
- The need for a good initial survey and risk assessment is clear, and typically a comprehensive monitoring programme is established to keep a check on progress.

The engineered solution

- If natural attenuation is not appropriate, then some form of engineered response is required, the selection of which will depend on a number of interlinked factors.
- Thus, the type and concentration of the contamination, its scale and extent, the level of risk it poses to human health or the environment, the intended eventual site use, the time available for remediation, available space and resources andany site-specific issues, all influence this decision.

Essential Features of Biological Treatment Systems:

- All biotechnology treatments have certain central similarities, irrespective ofthe specific details of the technique.
- The majority of applications make use of indigenous, resident microbes, though in some cases the addition of specialised organisms may be warranted.
- Thus, the functional biology may be described as aprocess of bioenhancement or bioaugmentation, or occasionally a mixture of both.

Cont..

- Bioenhancement concentrates solely on the existing microfauna, stimulating their activity by the manipulation of local environmental conditions.
- Bioaugmentation, by contrast, requires the deliberate introduction of selected microbes to bring about the required clean-up. These additions may be unmodified ‘wild type’ organisms, a culture selectively acclimatised to the particular conditions to be encountered, or genetically engineered to suit the requirements.
- Enzyme or other living system extracts may also be used to further facilitate their activity.
- Some land remediation methods simultaneously bioenhance resident bacteria and bioaugment the process with the addition of fungi to the soil under treatment.

Cont..

- In the final analysis, all biological approaches are expressly designed to optimise the activities of the various micro-organisms (either native to the particular soil or artificially introduced) to bring about the desired remediation.
- This generally means letting them do what they would naturally do but enhancing their performance to achieve it more rapidly and/or more efficiently.
- Effectively it is little different from accelerated natural attenuation and typically involves management of aeration, nutrients and soil moisture, by means of their addition, manipulation or monitoring, dependent on circumstance.
- However simple this appears,the practical implications should not be underestimated and careful understanding of many interrelated factors is essential to achieve this goal.
- For example,successful aerobic biodegradation requires an oxygen level of at least 2 mg/litre; by contrast, when the major bioremediation mechanism is anaerobic, the presence of any oxygen can be toxic.

Cont..

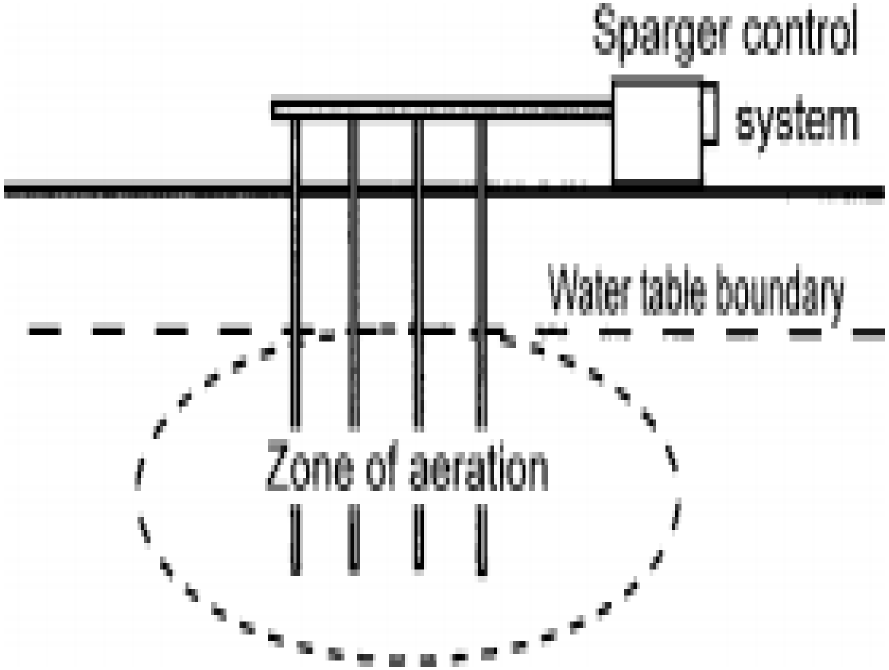
- The presence of certain organic chemicals, heavymetals or cyanides may inhibit biological activity; conversely, under certain circumstances microbial action may itself give rise to undesirable side effects like iron precipitation, or the increased mobilisation of heavy metals within the soil.

In situ techniques

- The fundamental basis of in situ engineered bioremediation involves introducing oxygen and nutrients to the contaminated area by various methods, all of whichultimately work by modifying conditions within the soil or groundwater.
- There are three major techniques commonly employed, namely biosparging, bioventing and injection recovery**.**
- The major benefits of in situ methods are their low intrusion, which enables existing buildings and site features to remain undisturbed, their relative speed of commencement and the reduced risk of contamination spread.

Biosparging

- Biosparging is a technique used to remediate contamination at, or below, the water table boundary,

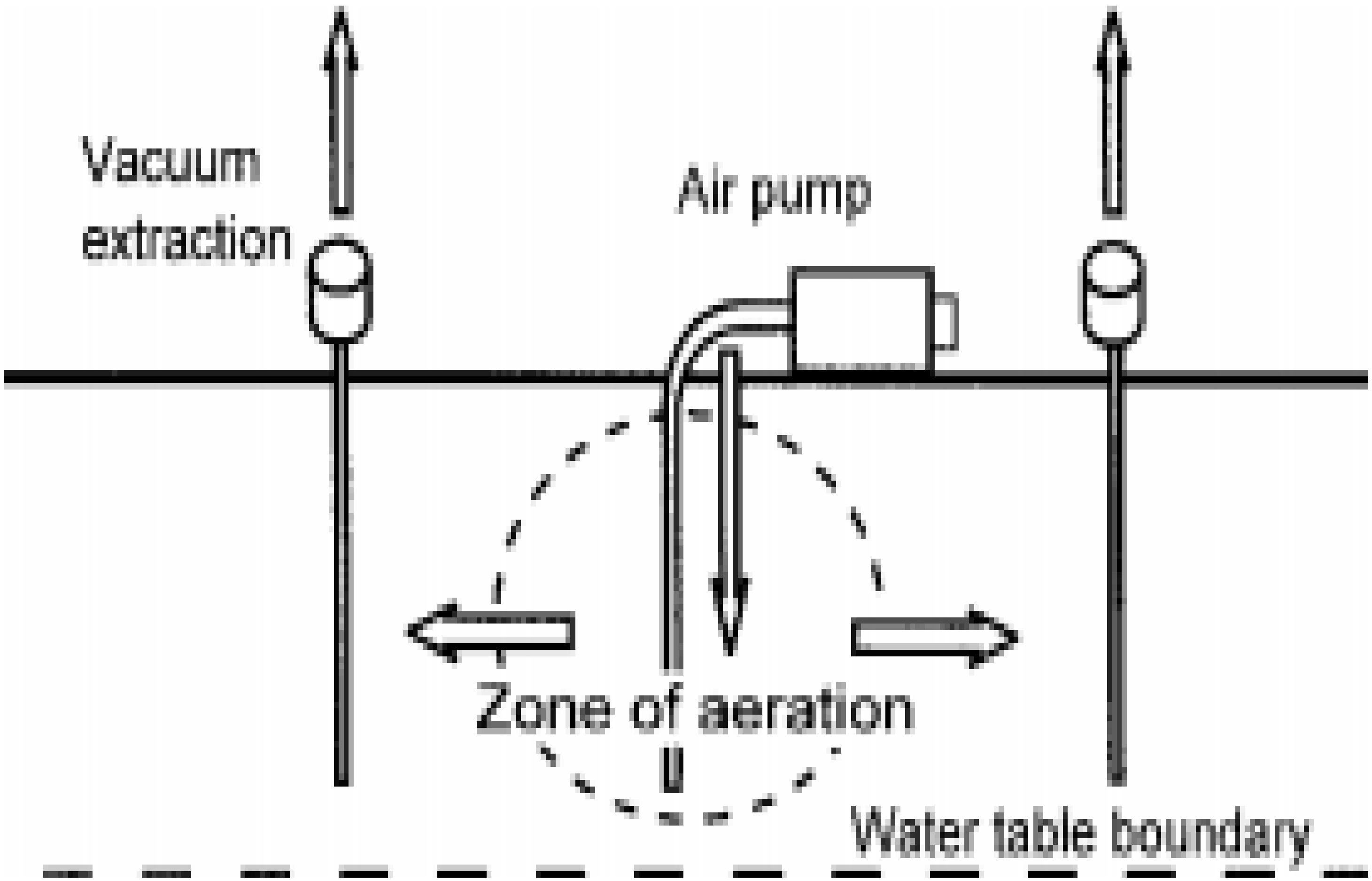


Cont..

- In effect, the process involves superaeration of the groundwater, thereby stimulating accelerated contaminant biodegradation.
- Though the primary focus of the operation is the saturated zone, the permeability of the overlying soil has a bearing on the process, since increased oxygenation of this stratum inevitably benefits the overall efficiency of remediation.

Bioventing

- Bioventing is a technique used to remediate contamination above the water table boundary.
- This process also involves superaeration, again with the intention of stimulating accelerated breakdown of the pollutants present, though this time it is taking place within the soil itself, instead of the groundwater.
- Bioventing is not generally suitable for remediating sites with a water table within one metre of the surface, nor for heavy or waterlogged soils, since air flow is compromised under these conditions.

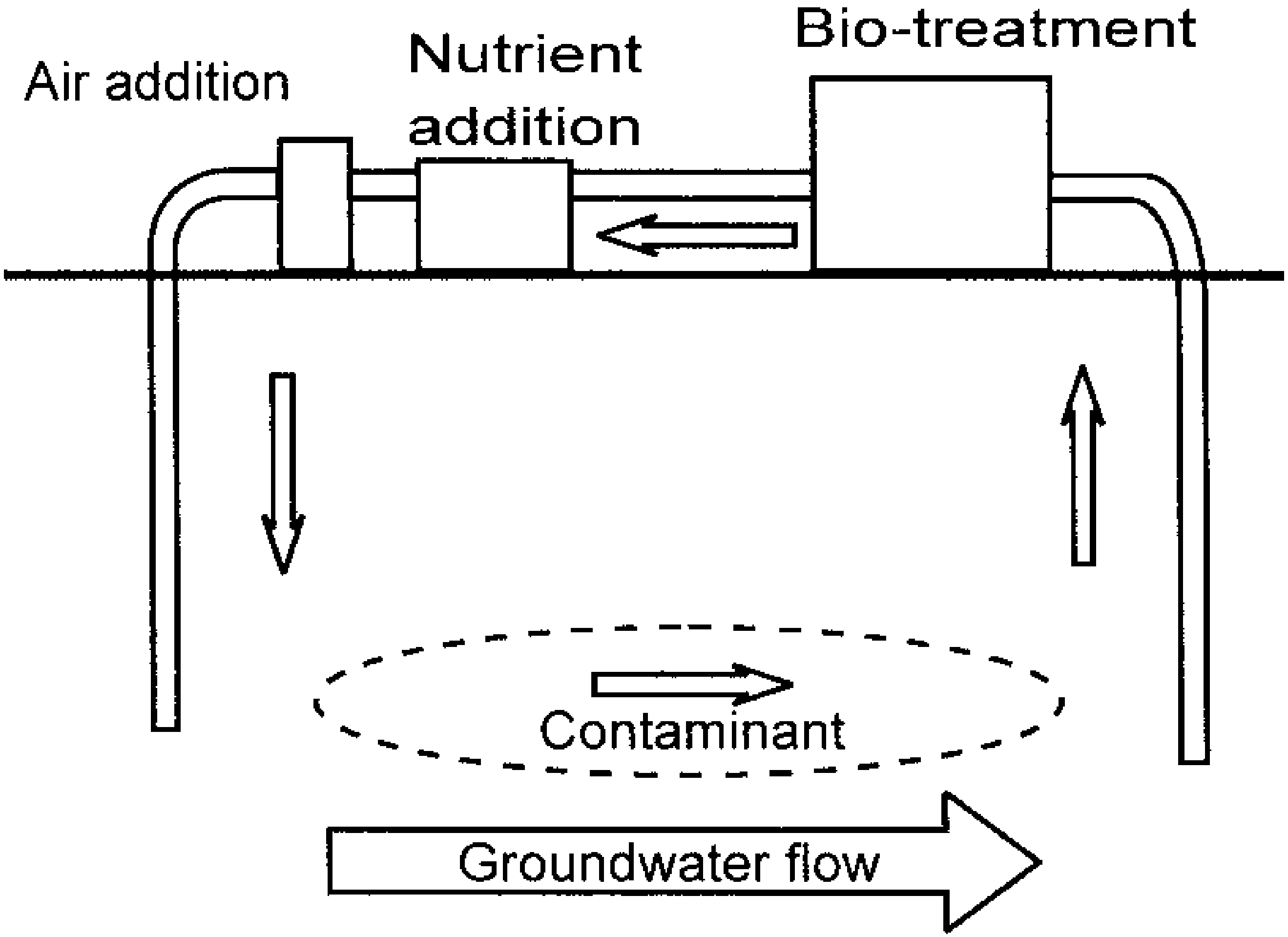

Vacuum extraction
Air pump
Zone of aeration
Water table boundary

Injection recovery

- The injection and recovery method, makes use of the movement of groundwater through the zone of contamination to assist the remediation process.
- This approach shares many functional similarities withthe preceding technologies, it is essentially more sophisticated and refined, with the biological treatment being effectively divided into two complementary stages.
- Thus, what may be considered a ‘virtual’ bioreactor is established within the soil matrix, with the actual clean-up activity taking place both within the groundwater and also externally to it.

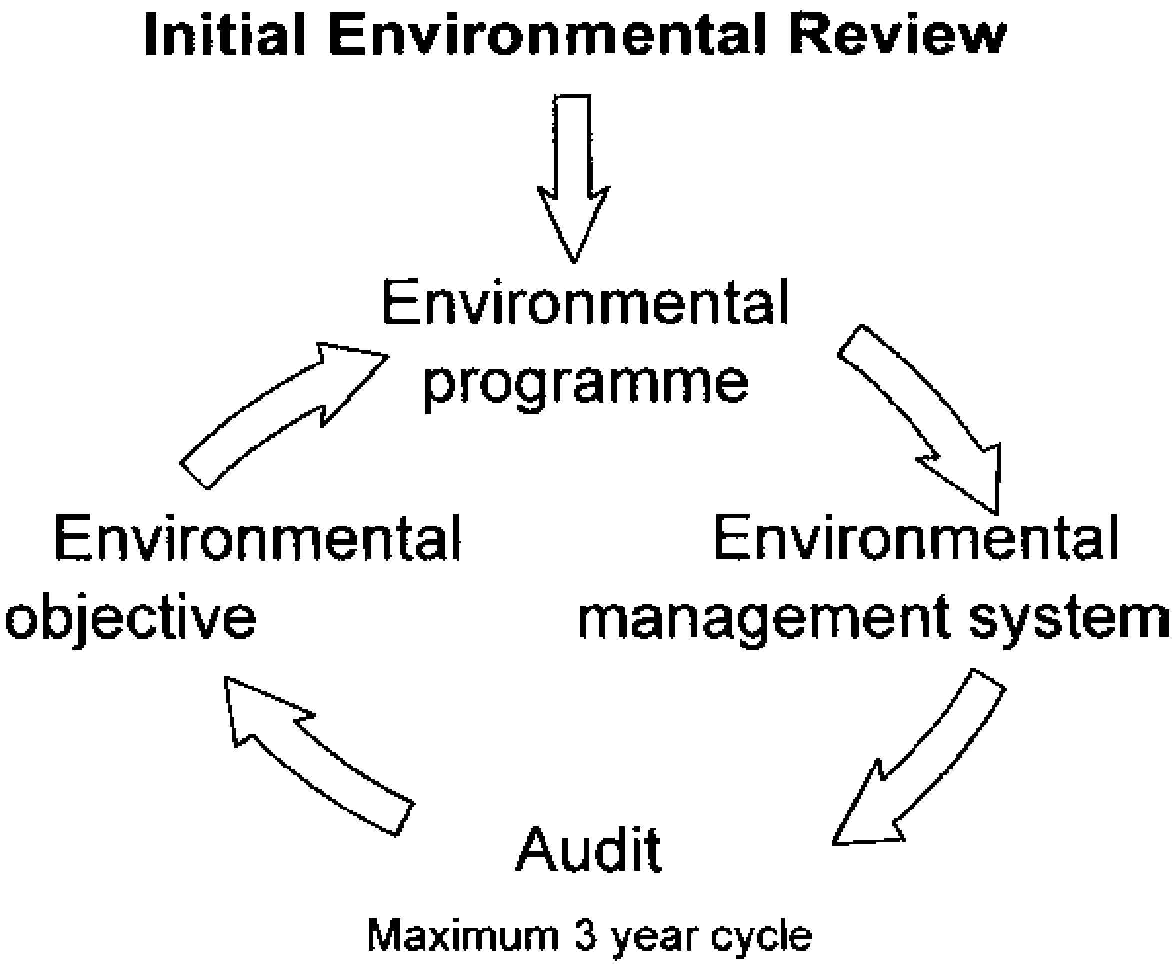
Cont..

- The major characteristic of this technique is the two-well system sunk into the ground, the ‘injection well’ and the ‘recovery well’, the former being located upstream’ of the latter.
- Nutrients and air are forced down the injection well, and as they flow through the contamination, they stimulate the growth and activity of the indigenous micro-organisms, which begin the process of remediation.
- Groundwater, now rich in contaminant, microbes, microbial metabolites and contaminant breakdown products is extracted via the ‘recovery well’ from beyond the contaminated zone.
- It then undergoes additional biological treatment above ground in an associated bioreactor vessel, frequently where it is subjected to
- highly aerobic conditions, before being reinjected, having been further replenished with air and nutrients.
- This cycle may be repeated many times in the course of treatment.


Bio-treatment
Nutrient addition
Air addition
Contaminant
Groundwater flow

Site monitoring for biotechnological applications

- Environmental monitoring is well established as a separate science in its own right and many notable books have been written to describe the various approaches and techniques relevant to its many practical applications.
- However, it is worth noting that for some sites it may be necessary to continue monitoring into the future.
- Under these circumstances, a comprehensive environmental management and audit scheme can be put in place to monitor environmental effects of such operations.
- The results would then, of course, feed back into the decision-making process and ultimately help to shape the ongoing environmental management regime of the site.



Initial Environmental Review

Environmental programme

Environmental management system

Audit

Maximum 3 year cycle

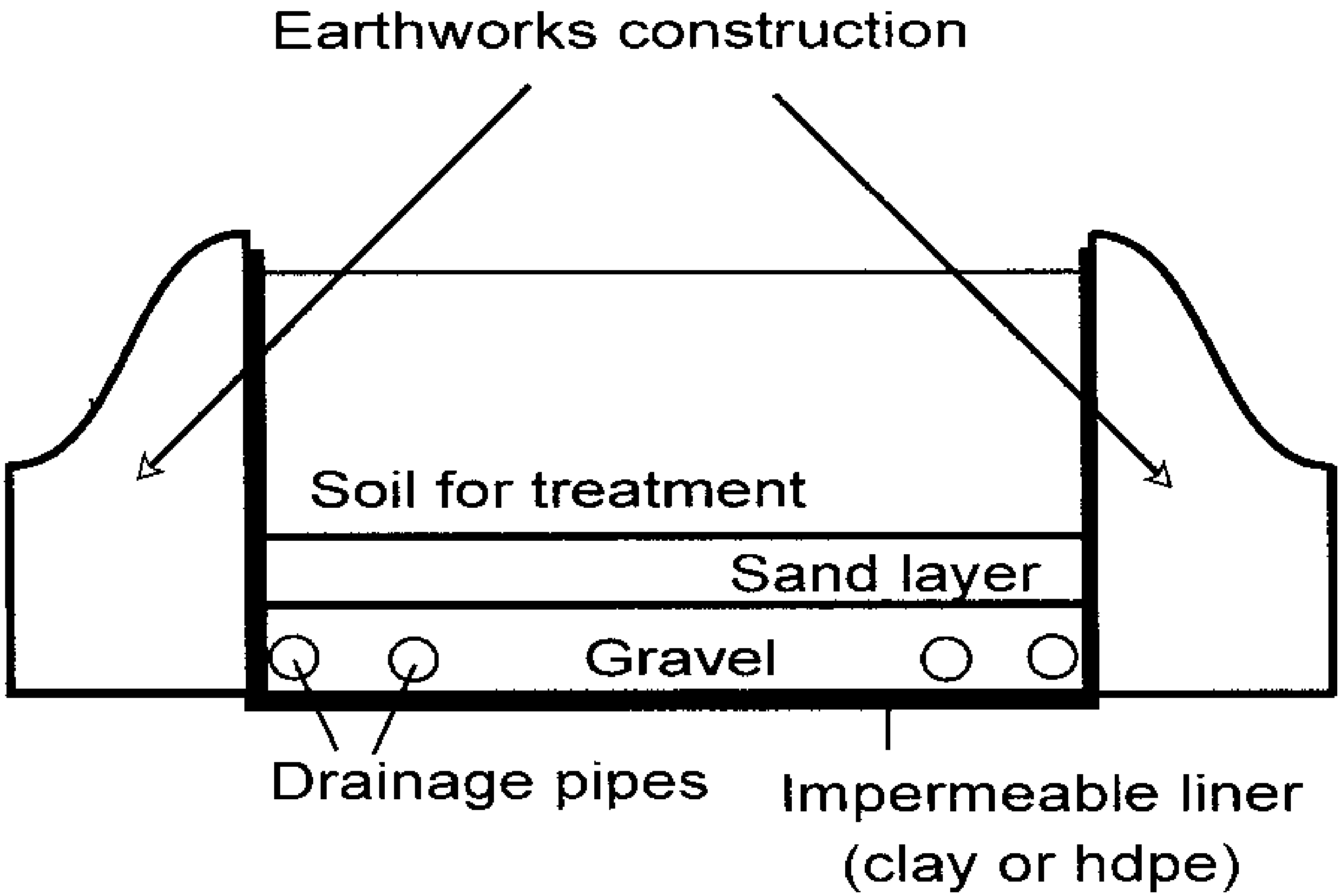
Environmental objective

Ex situ techniques

- Again, there are three principal approaches in common use, namely land farming,soil banking and soil slurry bioreactors.
- Though inevitably there are distinct similarities between all applications of bioremediation, for obvious reasons of fundamental biology, these techniques are generally more distinct and separate.
- The major benefits of ex situ methods are the greater ease of process optimisation and control, relatively shorter treatment time and the increased potential for the safe introduction of specialised organisms, if and as required.
- However the increased transport costs, additional land requirement and higher levels of engineering often combine to make these technologies more costly options.

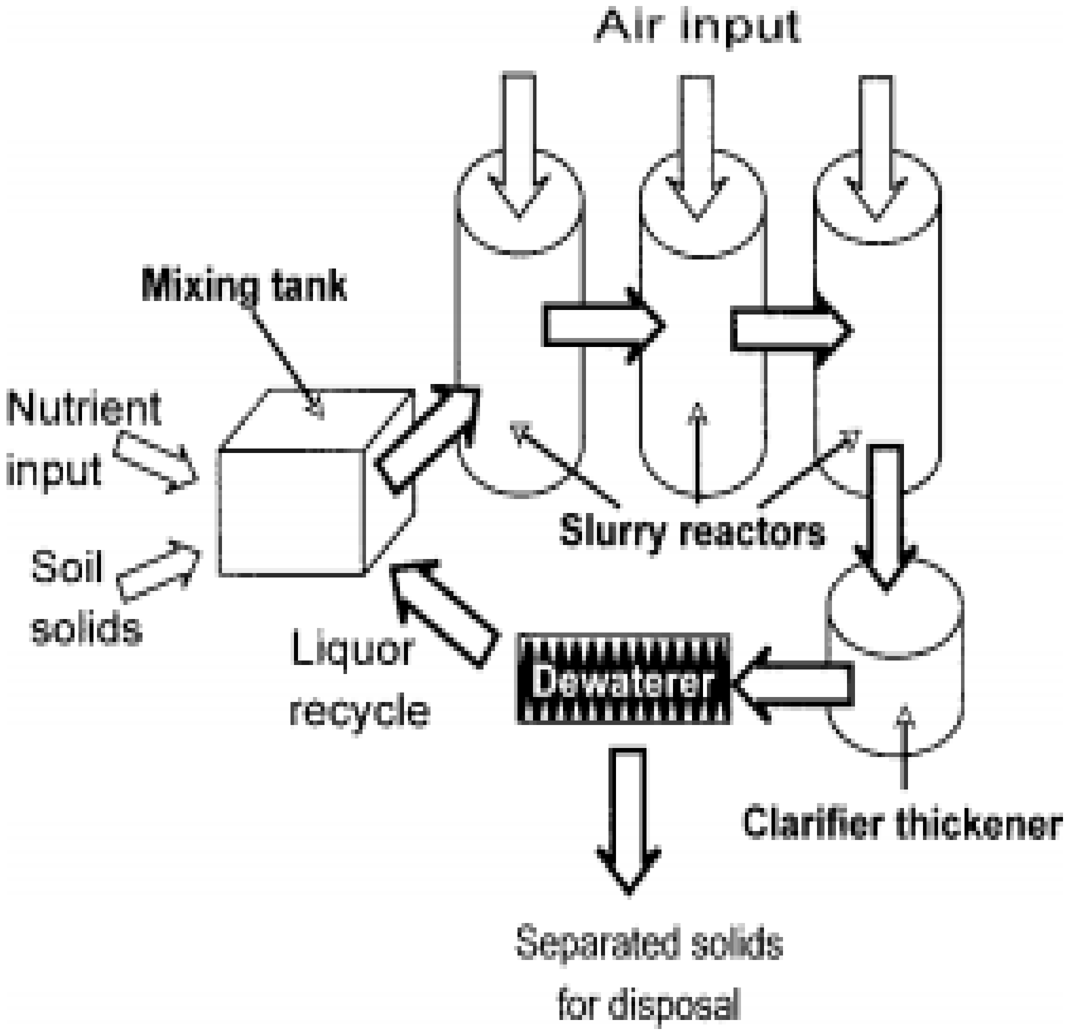
Land farming:

- This technique is effectively accelerated natural attenuation, taking place offsite, within constructed earthwork banking to provide what is essentially a low-tech bioreactor.
- The pretreatment stage involves the soil being excavated from site, screened for rocks, rubble and any other oversize inclusions before typically being stored prior to the commencement of actual remediation, either at the original location or on arrival at the treatment site.
- The processing itself takes place in lined earthworks isolated from the surroundings by an impermeable clay or high density polyethylene (HDPE) liner.


Earthworks construction
Soil for treatment
Sand layer
Gravel
Drainage pipes
Impermeable liner (clay or hdpe)

Soil slurry reactor

- In most respects, this system shares essentially similar operating principles to the activated sludge system which is used in treating effluents.
- After excavation, the soil is introduced into a mixing tank, where a slurry is produced by combining it with water.
- Nutrients are then added to stimulate microbial growth.
- The suspension formed is transferred to a linked series of wellaerated slurry reactors, and micro-organisms within them progressively treat the contaminants.
- Clarifiers and presses thicken the treated slurry and dewater it, the recovered liquid component being recirculated to the mixing tank to act as the wetting agent for the next incoming batch of soil, while the separated solids are removed for further drying followed by reuse or disposal.


Air input
Mixing tank
Nutrient input
Soil solids
Slurry reactors
Liquor recycle
Dewaterer
Clarifier thickener
Separated solids for disposal