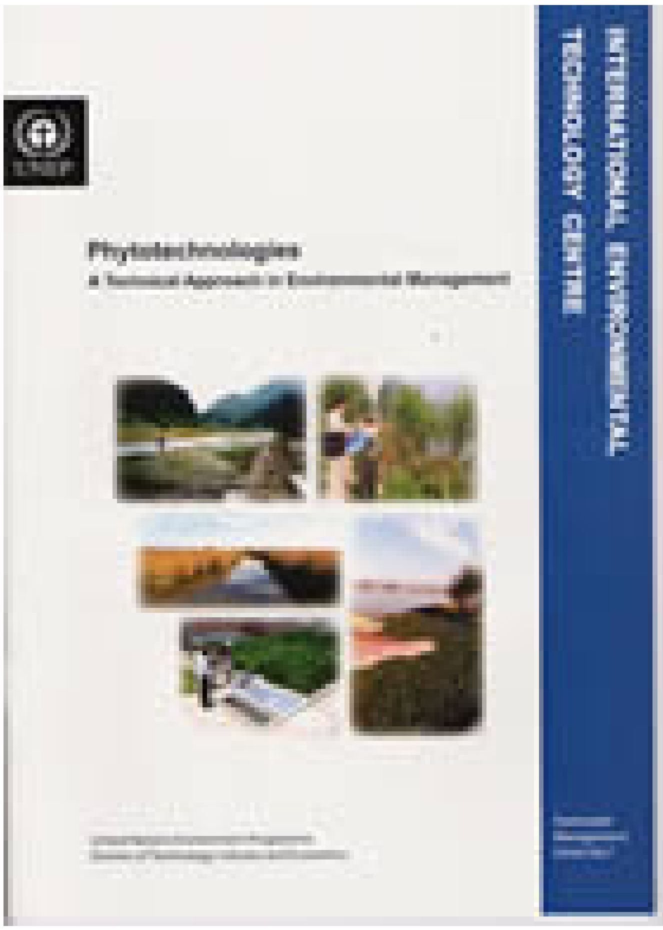
Freshwater Management Series No. 7

Phytotechnologies

A Technical Approach in Environmental Management



The purpose of this publication is to provide a conceptual overview of phytotechnologies and their importance in relation to various environmental problems and potential solutions. Although it does not address all aspects of phytotechnology, it does provide the basis of a conceptual framework for understanding the importance of ecosystems approaches in helping to achieve sustainable development objectives. It also examines the role of phytotechnology in relation to some key issues including integrated water resources management, urban environmental management, biodiversity and climate change.

(Webmaster's note: The glossary may be accessed by clicking the corresponding vocabulary set in blue type).

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About UNEP / DTIE

ACKNOWLEDGMENTS

GLOSSARY

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PREFACE

Role of the International Environmental Technology Centre

The International Environmental Technology Centre (IETC) was established by the United Nations Environment Programme (UNEP) in April 1994. The Centre's main function is to promote the application of environmentally sound technologies in developing countries and countries in transition. IETC pays particular attention to urban environmental problems and to the management of freshwater resources.

IETC's activities assist decision makers in governments and other organizations by:

- Raising awareness
- Facilitating the exchange of information,
- Building local capacity to make informed decisions,
- Promoting the development and demonstration of environmentally sound technologies leading to their adoption and use.

Purpose of this Publication

The purpose of this publication is to provide a conceptual overview of phytotechnologies and their importance in relation to various environmental problems and potential solutions. Although it does not address all aspects of phytotechnology, it does provide the basis of a conceptual framework for understanding the importance of ecosystems approaches in helping to achieve sustainable development objectives. It also examines the role of phytotechnology in relation to some key issues including integrated water resources management, urban environmental management, biodiversity and climate change.

The introductory section highlights the importance of an ecosystems perspective in the development and application of sustainable, environmentally sound technologies. It outlines the rationale for promoting appropriate, environmentally sound applications of phytotechnologies. It also describes how ecologically sound engineering practices and ecotechnologies can help society adapt to the dynamic self-organizing characteristics of natural systems. Section 2 describes the context for the beneficial application of phytotechnologies, including biodiversity, sustainable water, climate change and the importance of ecosystems and "natural capital". Following this, in Section 3, some examples of environmental applications of phytotechnology are presented. Section 4 summarizes some of the important factors that must be taken into account when considering the development and application of phytotechnologies, and section 5 highlights a number of important issues and possible actions that require further consideration. Appended to the publication is a glossary of relevant terms.

SUMMARY

Rational environmental management means making the best use of natural resources to meet basic human needs without destroying their sustaining environmental base. This requires a comprehensive understanding of the intersecting elements within the larger frame of development and implies the adoption and use of alternative, environmentally sound development strategies and associated technologies.

The term phytotechnology describes the application of science and engineering to examine problems and provide solutions involving plants . The term itself is helpful in promoting a broader understanding of the importance of plants and their beneficial role within both societal and natural systems. A central component of this is the use of plants as living technologies that provide services in addressing environmental issues.

Phytotechnology applications employ ecological engineering principles and hence are considered to be ecotechnologies. Ecotechnologies are based on the science of ecology and the consideration of the ecosystem as an integral part of any proposed human or societal interventions involving the natural environment. Ecotechnologies are dependent on the self designing capabilities of ecosystems and nature. The focus on, and use of, biological species, communities, and ecosystems distinguishes ecotechnologies from the more conventional engineering technology approaches which seldom consider integrative ecosystem-based approaches.

Combined with an understanding of hydrological and biogeochemical processes, phytotechnologies can be used to increase plant biomass and diversity and to regulate nutrients and water dynamics, thereby enhancing ecosystem carrying capacity and the resilience and functionality of ecosystems. This can lead to significant improvements in

water quality, enhanced biodiversity, improved agricultural production and potential bioenergy generation, as well as remediation and restoration of degraded ecosystems.

Environmentally beneficial applications of phytotechnologies involve the use of plants to augment the capacity of ecosystems to absorb impacts; and to manipulate the ecosystem to prevent, reduce or remediate pollution. Plants can be used to break down or sequester pollutants (sometimes making useful products as an added benefit), or replace certain products or processes that pollute with ones that do not. Applications can include the use of plants for the restoration of ecosystems and the hydrological cycle. Plants can also be used as indicators for monitoring and assessing ecosystems health.

The application of phytotechnologies in watershed management is complementary to Ecohydrology as both approaches involve the enhancement of the capacity of natural ecosystems to protect water resources and shoreline ecosystems. Phytotechnologies also play an important role with respect to climate change mitigation and adaptation, as plants are natural sinks for carbon dioxide. Furthermore, some phytotechnology applications involving the use of plants for housing, food, forage and sources of medicine can create employment. This is particularly important in developing countries.

Although the concept is not entirely new, the area of Phytotechnology is rapidly evolving and novel applications are continuing to emerge. Some examples of phytotechnology applications are:

- The use of plants to reduce or solve pollution problems that otherwise would be more harmful to other ecosystems. An example is the use of wetlands for wastewater treatment.
- The replication of ecosystems and plant communities to reduce or solve a pollution problem. Examples are constructed ecosystems such as ponds and wetlands for treatment of wastewater or diffuse pollution sources.
- The use of plants to facilitate the recovery of ecosystems after significant disturbances. Examples are coal mine reclamation and the restoration of lakes and rivers.
- The use of plants for societal benefits within the context of a managed ecosystem. Examples a re integrated agriculture and the management of renewable resources.
- The increased use of plants as sinks for carbon dioxide to mitigate the impacts of climate change. Examples of this are reforestation and afforestation.
- The use of plants to augment the natural capacity of urban areas to mitigate pollution impacts and moderate energy extremes. An example is the use of rooftop vegetation, or “greenroofs”.

An understanding of the potential and limitations of phytotechnologies is necessary for their successful application. Limitations include insufficient knowledge and expertise regarding plant selection and the factors that influence plant growth, as well as public and regulatory acceptance. Each application of phytotechnology involves site-specific considerations and should be evaluated on a case-by-case basis. The developers and proponents of phytotechnology systems must be able to demonstrate how phytotechnologies will meet environmental performance objectives while minimizing potential risks to human health.

The application of phytotechnology involves more than going to a site and planting seedlings, grass or some other type of plant. Phytotechnology is an in situ approach, whether used in the creation of artificial wetlands for water treatment, riparian recuperation and river/shore bank management, or site remediation, that requires careful consideration of site-specific characteristics and ecosystem interactions. Native plants are generally preferred for phytotechnology applications. In most applications, plants that are adapted to local conditions will have better chances of success than non-adapted plants. The use of mixed species of vegetation can also lead to greater chances of success than the use of monocultures, which may be highly prone to pests and reduce the natural genetic pool. Care should be taken not to introduce species of plants that are invasive or a nuisance that may cause greater damage than the expected benefits from their use.

The effectiveness of phytotechnology applications depends on having both broad-based and expert input into their development, adoption and ongoing monitoring. Governments, the private sector and citizens must all be involved, and systems for collecting, synthesizing and feeding back information and knowledge on phytotechnologies must be established and maintained. Issues and concerns must be addressed in a transparent, credible manner, and proactive strategies are required to ensure the responsible development and application of phytotechnologies.

I. INTRODUCTION – AN ECOSYSTEMS PERSPECTIVE

Our global interdependence and vulnerability has never been more pronounced. What happens on one part of the planet will have some kind of effect, at some time, on all other parts. Global change is a dynamic process that can only be understood from a holistic and ecological perspective. In describing the interactions of parts within the global ecosystem, the Brundtland Report refers to “a complex and interlinked ecosystem”, and the need to take into account “the system-wide effects of exploitation”. Emerging from this is the rationale for sustainable development and the importance of meeting the needs of the present without compromising the ability of future generations to meet their own needs.

Ecological processes are at the centre of these interactive natural, social and technological forces. On the one hand, through science and technology, humans are in the unique position of being responsible for their own environment. On the other hand, unexpected threats have arisen from the by-products of scientific and technological developments and in some cases ecosystems resilience and species diversity have diminished. Loss of plant and animal species can greatly limit the options of future generations; it is therefore important to ensure the conservation of species and the maintenance of biodiversity. It can be argued that the highest survival value for society is to maintain the integrity of the ecosystem and biotic community as a whole and that our human capacity to understand these processes confers upon us the responsibility to do this.

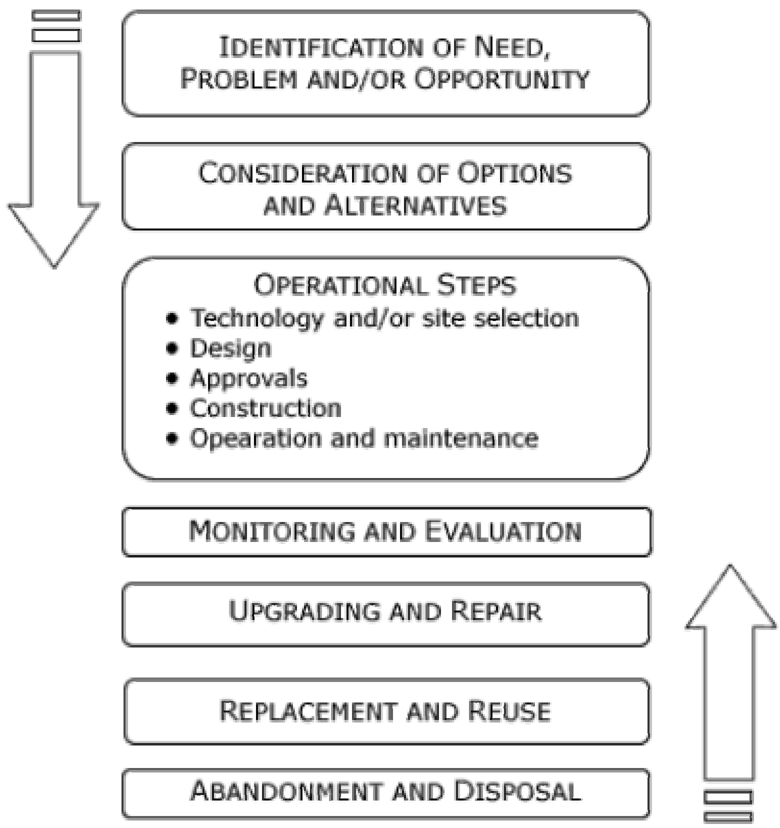
A. Environmentally Sound Technologies

Technologies reflect our cultural values and historically have altered the nature of human consciousness. Technologies, by their very presence, often force us into searching for solutions to problems that become defined as technological, even though many of these problems may not have been technological to begin with. Some believe that the problems created by one technology can be solved by a technological fix from another. They often ignore the fact that humans are both part of and dependent on nature. This is because the human and environmental consequences of technological choices and the extent to which we are shaped by technology are often obscured.

As shown in Table 1, all technologies undergo a similar development cycle, regardless of their origin or application. The first stage is the identification of a need, a problem or an opportunity. Second, there is a choice of alternatives. Next comes a series of operational steps, including - selection of sites and technologies; design; acquisition of appropriate rights and permissions; const ruction; operation and maintenance; and follow-up. Over time, there must be monitoring and evaluation and, if required, upgrading and repair. The final stage involves replacement or reuse, abandonment and disposal.

Rational environmental management means making the best use of resources to meet basic human needs without destroying the sustaining and regenerative capacity of natural systems. This requires a good understanding of the intersecting elements within the larger frame of development and implies the adoption and use of alternative, environmentally sound development strategies and related technologies.

Table 1: Technology Development Cycle



Environmentally Sound Technologies (ESTs) are technologies that have the potential for significantly improved environmental performance relative to other technologies. ESTs protect the environment, are less polluting, use resources in a sustainable manner, recycle more of their wastes and products, and handle all residual wastes in a more environmentally acceptable way than the technologies for which they are substitutes. ESTs are not just individual technologies. They can also be defined as total systems that include know-how, procedures, goods and services, and equipment, as well as organizational and managerial procedures for promoting environmental sustainability.

Defining environmentally sound technologies in an absolute sense is difficult since the environmental performance of a technology depends upon its impacts on specific human populations, biota and ecosystems, and the availability of supporting infrastructure and human resources for the management, monitoring and maintenance of the technology, as well as the sustainability of natural systems. The soundness of environmental technology is also influenced by temporal and geographical factors, to the extent that some technologies may be environmentally sound now but may be replaced in the future by even cleaner technologies.

Likewise, what is environmentally sound in one country or region may not be in another, unless it is redesigned or adapted to make it appropriate for addressing local needs. Thus the term environmentally sound technology can be applied to all technologies and their transition to becoming more environmentally sound; this ranges from basic technologies to fully integrated technologies. This definition captures the full life cycle flow of the material, energy and water in the production and consumption system. It also implies the development and application of environmentally sound technologies underpinned by more holistic environmental management strategies based on the characteristics of natural systems, which include: species diversity; resilience; adaptiveness; regenerative capacity; interconnectedness; spatial and temporal fluctuation; etc. Examples of ESTs that emulate natural processes are Ecological Engineering and Ecotechnologies.

Introduction - An Ecosystem's Perspective >

B. Ecological Engineering and Ecotechnologies

Historically, environmental problems have arisen primarily because of inappropriate decisions and a lack of understanding of the impact of these decisions upon the environment. New approaches must be developed and novel technological developments and engineering must function together in an integrated manner in order for social, economic and environmental benefits to be realized. Ecological engineering is an example of such an integrated approach.

Ecological engineering practices can help conserve and restore the environment through the integration of engineering and ecological principles. An ecologically sound approach to engineering takes into account that nature responds systematically, continuously and cumulatively. Ecological engineering operates within the natural system rather than infringing on or overcoming it. Solutions are developed to be as flexible and forgiving as possible, thus avoiding drastic and irreversible consequences when something goes wrong. To support such an approach, it is important to acquire knowledge and understanding about the dynamics of ecosystems and their particular vulnerabilities.

Ecological engineering and related ecotechnologies are dependent on the self-designing capabilities of ecosystems and nature. When changes occur, natural systems shift and food chains reorganize. As individual species are selected and others are not, a new dynamic order ultimately emerges that is usually better suited to the environment superimposed on it. This focus on, and use of, biological species, communities, and ecosystems distinguishes ecological engineering and related ecotechnologies from the more conventional engineering technology approaches which seldom consider integrative ecosystem-based approaches.

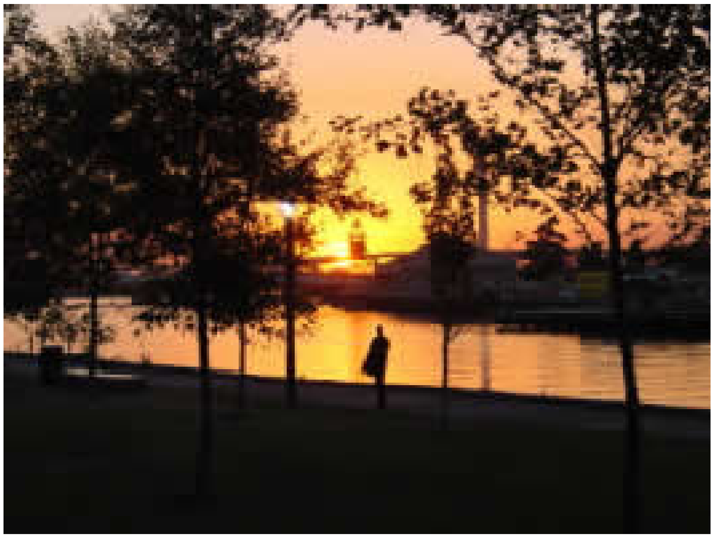
Ecological engineering involves identifying those biological systems that are most adaptable to human needs and those human needs that are most adaptable to existing ecosystems, while recognising that it is counterproductive to eliminate or even disturb natural ecosystems unless absolutely necessary. Ecological engineering and ecotechnology applications also emphasize understanding of the entire ecosystem rather than components of the system in isolation from one another. Decision support tools such as modelling and cost -benefit analysis are important, as ecosystem solutions cannot be determined by simply adding up the parts to make a whole. Table 2 provides some examples of ecological engineering and ecotechnology applications.

Table 2. Some Examples of Ecological Engineering and Ecotechnology Applications

Application	Examples
Ecosystems are used to reduce or solve a pollution problem that would otherwise be harmful to other ecosystems.	Wastewater recycling in wetlands; sludge recycling
Ecosystems are imitated or copied to reduce or solve a resource problem.	Reconstructed wetlands; integrated fishponds
The recovery of an ecosystem is nurtured after significant disturbance.	Surface coal mine restoration; lake and river restoration; restoration of hazardous waste sites
Existing ecosystems are modified in an ecologically sound way to solve an environmental problem.	Biomanipulation of species; biological control of eutrophication processes
Ecosystems are used for the benefit of humans without destroying the ecological balance.	Sustainable agro-ecosystems; sound renewable resource harvesting

Introduction - An Ecosystem's Perspective >

C. Phytotechnology



The term **phytotechnology** describes the application of science and engineering to study problems and provide solutions involving **plants**. Although the term is not widely used, it is useful in promoting a broader understanding of the importance of plants and their beneficial role within both societal and natural systems. Underlying this concept is the use of plants as **living technologies**to help address environmental challenges.

Phytotechnology applications employ **ecological engineerin**g principles and are considered to be **ecotechnologies**. Hence phytotechnologies are based on the science of ecology and consider the ecosystem as an integral component of human and societal interventions involving the natural environment.

A related term is **biotechnology**, which refers to the application of science and engineering to study problems and provide solutions involving **living beings**. The term biotechnology can also refer to the manipulation of the genetic structure of cells to produce modified organisms with an augmented capacity to perform certain functions. Table 3 summarizes these definitions.

Table 3: Defining Phytotechnology

<table>
<tr><td>eco = living systems, ecological</td><td rowspan="3">TECHNOLOGY = the application of science and engineering to study problems and provide solutions</td><td>ecotechnology = the application of science and engineering to study problems and provide solutions involving ecological systems</td></tr>
<tr><td>PHYTO = plant, flora, vegetation</td><td>PHYTOTECHNOLOGY = the application of science and engineering to study problems and provide solutions involving plants</td></tr>
<tr><td>bio = life, of living beings, biological</td><td>biotechnology = the application of science and engineering to study problems and provide solutions</td></tr>
</table>

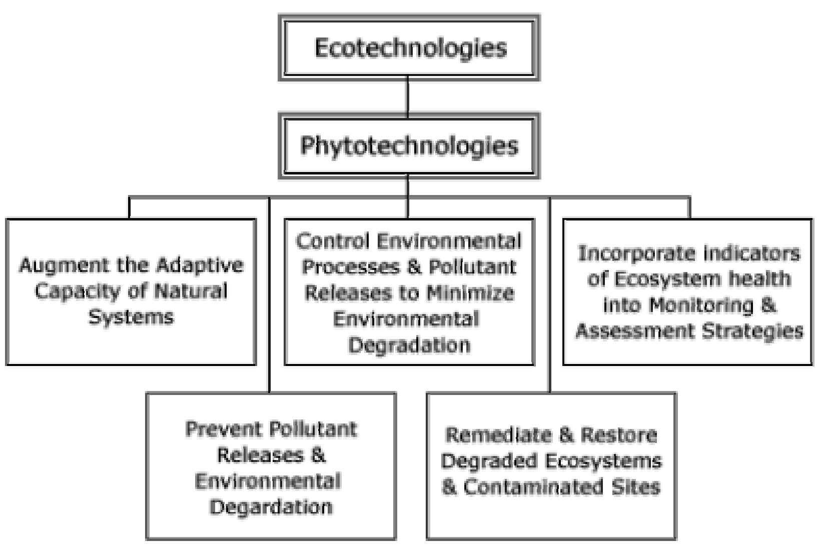
		involving living beings

Just as there are many different applications of biotechnology, there are also many different applications of phytotechnology. Some of these applications are well established in sectors such as medicine, agriculture and forestry to name a few. There are also many important environmentally related applications.

As shown in Table 4, the environmentally beneficial applications of phytotechnologies can generally be divided into five categories: augmenting the adaptive capacity of natural systems to moderate the impacts of human activities; preventing pollutant releases and environmental degradation; controlling pollutant releases and environmental processes to minimize environmental degradation; remediation and restoration of degraded ecosystems; and incorporating indicators of ecosystem health into monitoring and assessment strategies.

The integrated ecosystems management component of this focuses on the use of phytotechnologies to augment the capacity of natural systems to absorb impacts. The prevention component involves the use of phytotechnologies to avoid the production and release of environmentally hazardous substances and/or the modification of human activities to minimize damage to the environment; this can include product substitution or the redesign of production processes. The control component addresses chronic releases of pollutants and the application of phytotechnologies to control and render these substances harmless before they enter the environment. The remediation and restoration component embodies phytotechnologies and methods designed to recuperate and improve ecosystems that have declined due to naturally induced or anthropogenic effects. The monitoring and assessment component involves the use of phytotechnologies to monitor and assess the condition of the environment, including releases of pollutants and other natural or anthropogenic materials of a harmful nature.

Table 4: Environmentally Beneficial Applications of Phytotechnologies



Some specific examples of phytotechnology applications include:

- The use of plants to reduce or solve pollution problems that otherwise would be more harmful to other ecosystems. An example is the use of wetlands for wastewater treatment.
- The replication of ecosystems and plant communities to reduce or solve a pollution problem. Examples are constructed ecosystems such as ponds and wetlands for treatment of wastewater or diffuse pollution sources.
- The use of plants to facilitate the recovery of ecosystems after significant disturbances. Examples are coal mine reclamation and the restoration of lakes and rivers.
- The increased use of plants as sinks for carbon dioxide to mitigate the impacts of climate change. Examples of this are reforestation and afforestation.
- The use of plants to augment the natural capacity of urban areas to mitigate pollution impacts and moderate energy extremes. An example is the use of rooftop vegetation, or “ greenroofs”. More information and examples about the use and applications of phytotechnology is presented in Section 3.

D. UNEP’S Interest in Phytotechnology

The United Nations Environment Programme (UNEP) recognizes the importance of streamlining the integration of environmental and development strategies to make them more coherent in achieving sustainable development objectives. A central role for UNEP is to encourage decision makers in government, industry and business to develop and adopt policies, strategies and practices that are cleaner and safer, use natural resources more efficiently, and reduce pollution risks to human beings and the environment. Within UNEP, the Division of Technology, Industry and Economics (DTIE) is responsible for promoting the adoption and transfer of environmentally sound technologies and management practices.

In support of this, and as part of UNEP/DTIE, the International Environmental Technology Centre (IETC) focuses on issues related to urban environmental problems and the management of freshwater basins. IETC pursues a results-oriented mandate which involves:

- Improving access to information on environmentally sound technologies (ESTs),
- Fostering technology cooperation, partnerships, adoption and use of ESTs, and

• Capacity building.

IETC’s principal interest in promoting the concept of phytotechnology relates to water, urban environmental management issues and climate change. Linked to this is the integrated approach of the Centre in supporting the principles and concepts of biodiversity and sustainable development.

The sections which follow present some of the global issues which depend on integrated solutions and various approaches that can be used in incorporating phytotechnologies as part of these solutions. The environmental benefits of phytotechnologies in the management of ecosystem resources is also discussed, as well as the prevention, control and remediation of pollution and environmental degradation through the application of ecosystems approaches.

II. GLOBAL ISSUES REQUIRING INNOVATIVE SOLUTIONS

Sustainable development is a complex process of purposeful change in the attitudes, behaviours, and institutions of human societies. An ecological viewpoint is essential to any valid concept of development because the development process itself is inherently ecological. In other words, it is a process of purposeful change in the systematic interrelationships of living and inanimate things as they have evolved and continue to evolve in a biosphere dominated by human society.

Biodiversity, biosafety, integrated water resources management, urban environmental management, climate change, and the valuation of natural capital are global issues of concern where phytotechnologies can play a beneficial role.

A. Biodiversity and the Biodiversity Convention

Biological diversity can be defined as the variability among living organisms and the ecosystems of which they are a part. There are three levels of diversity and the interactions amongst these different levels must be considered simultaneously. The three different levels are: genetic diversity (diversity within species, from the molecular level to the level of populations); species diversity (the richness of species in a given place at a given time); and ecological diversity (the heterogeneity of ecosystems, habitats and landscapes).

The importance of biological diversity lies not merely in conservation-related aspects. Genetic and molecular diversity focusing on the selection of plants and animals for greater productivity is an important economic driver. Equally important, at a higher level of ecological diversity, are issues such as land use, landscape dynamics and sustainable tourism.

Anthropogenic activities increasingly disturb the integrity of global biodiversity. Pollution, the introduction of exotic species, unsustainable agricultural practices, urban sprawl and climate change all contribute to the loss of biodiversity through ecosystem disruption and habitat destruction. Furthermore, although some developing countries may be rich in biodiversity, their development, food sufficiency and survival policies usually do not consider species conservation as a high priority.

Genetic diversity has a positive function in the durability of biological systems and hence genetic erosion is a significant issue. Of particular concern is the rate at which species are currently becoming extinct, the threat of dysfunction in major ecosystems such as tropical rainforests, and the reduction in genetic resources of modern agriculture resulting from the widespread distribution of high-yield strains and varieties.

The United Nations Convention on Biological Diversity is a multilateral instrument designed to respond to this ecological crisis. It was preceded by a number of other international legal agreements on species and habitat protection. The objectives of the Convention, which came into force in December of 1993, are the conservation of biological diversity, the sustainable use of biological resources, and the fair and equitable sharing of benefits from genetic resource use. The United Nations Environment Programme (UNEP) serves as the Secretariat for this Convention.

An important element of the Convention is that the Parties commit to conserve biodiversity in natural settings through the establishment, management and maintenance of parks and protected areas. The Convention on Biological Diversity requires that the Parties develop legislative provisions to protect endangered species, including plants. It stipulates that the Parties agree to develop or maintain necessary regulatory provisions for the protection of threatened species and populations. Other aspects under the Convention include the requirement to:

- establish systems of protected areas, manage biological resources, rehabilitate degraded ecosystems, regulate risks of living modified organisms, control alien species, protect threatened species
- respect, preserve and maintain knowledge, innovations and practices of indigenous and local communities embodying traditional lifestyles relevant for the conservation of biodiversity and sustainable use of biological resources
- facilitate access to genetic resources, on mutually agreed terms and under prior informed consent of the Party providing such resources.

Another important international instrument is the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which provides for the protection of wild species against overexploitation through international trade, by regulating the international movement of animal and plant species. CITES, which came into effect in

1975, operates through an import/export permit system that controls or prohibits trade in approximately 48,000 species and subspecies of wildlife. Products made from endangered species of plants and animals are also regulated.

B. Biotechnology and the Biosafety Protocol

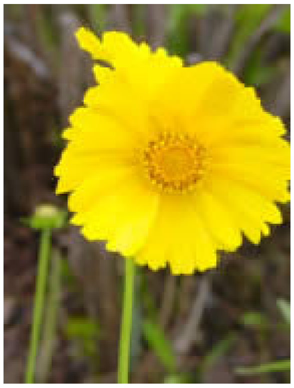
Biotechnology is an enabling technology that offers the potential for cleaner and more efficient alternatives to many wasteful processes and polluting products, including new techniques to treat solid and liquid wastes. There are numerous examples of biotechnology applications which can dramatically improve quality of life. Researchers are finding new drugs, new therapies and new ways of controlling diseases. Energy derived from plants can substitute for non-renewable fossil fuels. New high-yield crop varieties and those resistant to unfavourable weather conditions and pests are revolutionizing agriculture.

Although biotechnology can provide many innovative environmental management solutions, some biotechnology applications have significant social and environmental implications. Genetic engineering, for example, enables genes and their properties to be transferred from one organism, unconstrained by natural reproductive barriers. This raises concerns about possible accidental releases of genetically modified organisms (GMOs) and their safe containment, and in particular how to:

- assess the medium-term effects of GMOs on natural systems,
- contain and control the dispersal of micro-organisms,
- develop and apply national laws and international standards.

If society is to accept the consequences of these innovations, and the generalized spread of GMOs, the inherent risks must be correctly evaluated. In the absence of scientific certainty, common sense requires the application of the precautionary principle, which holds that preventative measures should be taken when a serious or potentially irreversible threat exists.

Responding to this challenge, in January 2000, the Conference of the Parties to the Convention on Biological Diversity adopted a supplementary agreement to the Convention known as the Cartagena Protocol on Biosafety on. The Biosafety Protocol reflects growing public concerns about the potential risks of biotechnology and GMOs, including genetically altered food crops that have been modified for greater productivity or nutritional value, or for resistance to pests or diseases. The Protocol seeks to protect biological diversity from the potential risks posed by living modified organisms resulting from modern biotechnology. It is the first binding international agreement covering living modified organisms that cross national borders because of trade or accidental releases.



The Biosafety Protocol establishes a procedure for ensuring that countries are provided with the information necessary to make informed decisions before agreeing to the import of such organisms into their territory. It enshrines the "precautionary approach" as a principle of international environmental law and puts environment on a par with trade-related issues in the international area. The aim is to ensure that recipient countries have both the opportunity and the capacity to assess risks involving the products of modern biotechnology.

The Protocol includes an International Register on Biosafety managed by UNEP, which deals with the safe development, transfer and application of biotechnology. Many developing countries lack the technical, financial, institutional and human resources to address biosafety. The Biosafety Protocol has therefore established a Biosafety Clearing-House to help countries build the necessary capacity for assessing and managing risks, establishing adequate information systems, and developing expert human resources in biotechnology. In this regard, UNEP cooperates with the Biosafety Information Network and Advisory Service (BINAS) of the United Nations Industrial Development Organization (UNIDO).

An open dialogue on the positive and negative aspects of biotechnology is needed in order to ensure that the objectives of sustainable development and biological diversity are not compromised. Once a genetically engineered product has been manufactured, it should be tested for possible human health effects and environmental risks. Furthermore, effective strategies and operational procedures are necessary to ensure that waste streams do not become a route for accidental releases of genetically engineered organisms. Some feel that until these questions are answered in a satisfactory way, the development of biotechnology should be limited to the effective use of existing, naturally occurring genetic material.

Underlying this is the reality that a wealth of genetic diversity already exists throughout the world, especially in tropical areas such as rain forests. For example, more than 90% of the world's half million plant species have never been assessed for their commercial value. Many pharmaceutical products are derived from naturally occurring organisms. Also, wild plants are the source of gums, oils, resins, dyes, tannins, vegetable fats and waxes, insecticides, and many other compounds that can help in the manufacture of fibres, detergents, starch and other products. In light of this, there needs to be a greater appreciation of the fundamental role of traditional rural communities in managing biodiversity. To protect traditional knowledge and foster responsible resource management, policies should favour projects and initiatives that are more closely integrated into economic and social life, in which local communities have a major part to play.

C. Integrated Water Resources Management and Ecohydrology

Over a billion people worldwide lack access to adequate water, and close to two billion suffer the consequences of poor sanitation; millions of people die each year from contaminated water. Water quality, expressed as secondary pollution and toxic algal blooms, continues to decline in aquatic ecosystems around the world. Furthermore, thousands of rivers, lakes and reservoirs are continuously affected directly or indirectly by human activities causing enormous environmental problems related to biodiversity, ecosystem functioning and preservation of the water cycle. These impacts are sobering evidence that the prevailing approach to catchment-scale water management does not guarantee sustainable water use. Technical approaches to pollution control, such as sewage treatment plants and regulation of hydrological processes for flood and drought control, are important but by themselves not sufficient. Purely technical controls, without understanding and consideration of biota dynamics, reflect a trial and error approach to water management rather than the implementation of a policy toward sustainable use of water resources.

In most parts of the world, urbanisation has caused progressive occupation and development of open land and land reclamation from water basins, causing changes in ecology and hydrology. Heavy consumption of water in cities, combined with suburban sprawl resource overexploitation and the technical, political and economic challenges of meeting water demands, has created growing pressure to build in new areas and maintain older systems. In developing countries, providing enough safe water to meet basic human needs is a serious problem. Areas without adequate water supply tend to remain underdeveloped because of widespread disease and unsanitary living conditions. Where infrastructure does exist, water resource managers are struggling to meet more stringent water quality goals and regulations.

Historically, problems of poor water supply and inadequate wastewater treatment have persisted because of limited resources and funding, and an absence of effective policies, planning, management practices and regulations. Even when funding has been available, the conventional response has been to build large, centralised treatment plants, often without sufficient consideration of the need to overhaul and maintain existing supply infrastructure. The potential for degraded infrastructure to jeopardise safe water supply is often ignored. For example, it is not unusual for poor distribution systems to leak 50% or more. Similarly, the construction and operating costs of conventional wastewater treatment systems are often too high, and much of the world's wastewater is discharged untreated. As a result, there is growing interest in developing more affordable, decentralized solutions based on natural systems which combine natural wastewater purification and nutrient recycling, including the use of phytotechnologies, such as constructed wetlands, for wastewater treatment.

A watershed planning and management strategy within a hydrologically defined area provides a coordinating framework for water supply protection, pollution prevention and ecosystem preservation. Although watershed strategies vary, they should be based on ecohydrology, the integrated study of ecosystems and hydrological characteristics and processes and their combined potential to influence water dynamics and quality. Ecohydrology requires an understanding of the temporal and spatial patterns of catchment-scale water dynamics which are determined by four fundamental components: climate, geomorphology, plant cover/biota dynamics and anthropogenic modifications. A more efficient approach to water quality and ecosystem integrity requires not only the reduction or elimination of pollution, but in parallel, an augmentation of the effectiveness of potential tools to manage the dynamics of excess nutrients, pollutants, mineral and organic matter in the landscape. This can be done by reducing human impacts and by regulating the aquatic and terrestrial biota in the catchment. One of the most efficient ways to control biota dynamics is through the regulation of hydrological processes by:

- increasing watershed water retention through reforestation and restoration of land/water ecotones,
- enhancing in-stream retention of water sediments and nutrients through river renaturisation and wetland restoration,
- amplifying biogeochemical cycles such as denitrification through wetland inundation.

Recent and ongoing research has greatly increased our understanding of hydrological dynamics, as well as the biotic and biogeochemical dynamics in freshwater ecosystems and land/water ecotones. The application of biotic processes can facilitate self-purification in aquatic ecosystems, significantly reduce the costs of water quality maintenance, and expand the repertoire of management tools which can be applied to freshwater resources. The application of ecohydrological concepts in watershed management also relies on the existence and manipulation of plants understood in terms of species distribution and interactions.

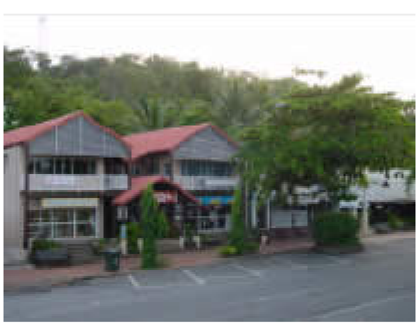
The United Nations Governing Council has directed IETC to play a central role in the transfer of ESTs for freshwater management in developing countries. As part of this responsibility, IETC is working with the Ecohydrological Programme of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and other organisations to promote a broader understanding of the combined benefits of phytotechnologies and ecohydrological applications.

D. Cities as Sustainable Ecosystems

Cities are pollution sources and people living in them utilize resources and generate waste. Due to inadequate systems and poor planning, cities are disproportionately driving global warming, deforestation, and increasing water scarcity. The world's cities take up just two percent of the Earth's surface, yet account for roughly 78 percent of the carbon emissions from human activities, 76 percent of industrial wood use, and 60 percent of the water tapped for use by people.

Cities import resources and export pollutants, but have limited carrying capacities. If the carrying capacity of a city is eroded, it becomes increasingly difficult, if not impossible, to achieve sustainable development goals. For example, the trucking of garbage to landfills outside of a city becomes increasingly costly, the further from the city the landfills are located. Also, the importation of fresh water to replenish a city's depleted aquifers becomes increasingly costly, the greater the distance the water must be piped. One of the challenges for the future will be our ability to reform urban systems so that they mimic the metabolism of nature. Rather than devouring water, food, energy, and processed goods, and then belching out the remains as pollutants, cities need to align their consumption with realistic needs, produce more of their own food and energy, and put much more of their wastes to use.

The concept of "Cities as Sustainable Ecosystems", or CASE, provides a framework for examining and understanding the interactions of urban activity and the environment and how these can be transformed into a sustainable relationship. CASE is the multidisciplinary study of urban and economic systems and their linkages with natural systems. CASE provides a conceptual framework upon which understanding and reasoned improvement of current practices can be based. One area where phytotechnologies can contribute to the objective of CASE involves biodiversity in cities. In preserving biodiversity, cities can exercise two strategies – they can enhance and reinforce biodiversity throughout their domain, and they can promote the conservation of threatened species.

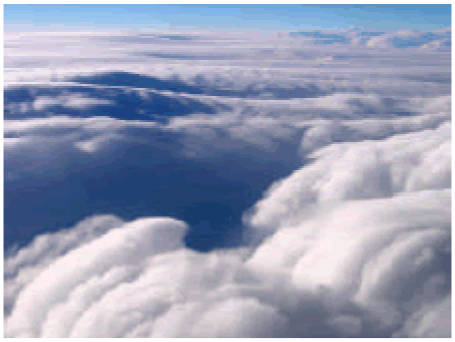


The presence of nature within the city can take many forms. Natural systems tend to persist in the urban setting where strong geological features (i.e., rivers and geological contours) and land unsuitable for building exist. The initial concepts instrumental in guiding the construction of the city are also important factors, given that the density of buildings and infrastructure leaves either more or less room for nature. In certain cities, zoning regulations call for plenty of open space, which is usually developed as green space. There are typically two types of green space within cities – the natural systems, in which human intervention has been minimised, and which are composed of a high proportion of indigenous species; and the cultivated biological areas deliberately created by humans to embellish the city, usually characterized by introduced species or horticultural plantings requiring human intervention. The distinction between these two types of green space is an oversimplification. In reality, there is considerable overlap between spaces deliberately developed by humans making use of indigenous species (i.e., the concept of the "natural" garden) and introduced species adapting to the city and spreading without outside intervention. This overlap is important as cities continue to evolve in ways that integrate the natural and built environment. This is an area where phytotechnologies can play a beneficial role.

The ecology and biodiversity in a city go hand in hand. In natural spaces comprised of different types of vegetation, a natural urban ecosystem can function and varied urban wildlife can flourish. Many horticultural species (e.g. conifers or many-branched shrubs) are often well adapted to the microclimate of the city, and can provide shelter for urban wildlife. Tall trees, particularly if planted in belts, can have a positive impact on the local environment and improve air and water quality. Urban biological diversity also plays an important educational role in providing opportunities for observing wildlife. It sensitizes humans to the green spaces and natural systems which balance the "inorganic" reality of buildings and urban infrastructure.

E. Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC), adopted in 1992, states that: "Each Party shall limit its anthropogenic emissions of greenhouse gases and protect and enhance its greenhouse gas sinks and reservoirs". Under the UNFCCC, a "sink" is defined as "any process, activity or mechanism which removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas from the atmosphere." Currently, photosynthesis, a natural biological process, is the only process considered by the UNFCCC to act as a sink by removing carbon dioxide from the atmosphere. However, it is also widely recognized that anthropogenic land uses and land use changes can alter the magnitude and rate of natural exchanges of greenhouse gases. Due to the dominating influence of natural forests and large areas in agriculture, the issue of carbon sinks in relation to land-use, land-use change and forestry is of particular interest.



Humans interact with land in many different ways and the linkages between humans and plants in relation to climate change are multiple, centering on forests, both boreal and tropical, as well as agricultural lands and wetlands. Global forests fix a high proportion of atmospheric carbon dioxide. Each forest ecosystem has its own profile, depending on its state of succession, climatic factors and expos ure to natural and human disturbances.

Although the primary source of anthropogenic carbon dioxide emissions is the use of fossil fuels, deforestation contributes significantly to the net increase of atmospheric carbon dioxide. Deforestation can be defined as the conversion of forested land to other land-use. This includes forest conversion for permanent land-use changes such as agriculture, as well as the development of permanent infrastructure, such as highways. Some of the other factors affecting GHG emissions include the harvest and use of wood commodities, and the establishment and operation of forest plantations. Forests also contain a high proportion of the world's biodiversity and as these areas are deforested, biodiversity is threatened. Policies to reduce deforestation are an important element of an overall strategy to address both global climate change and biodiversity. Two important areas of activity are afforestation and reforestation.

Afforestation is the planting of new forests on lands which, historically, have not contained forests. One of the principal challenges of afforestation efforts is the difficulty of convincing individual landowners to allow their marginal agricultural and other land to become forested land. Afforestation is likely to proceed slowly at first, as programs and policies are implemented, financing mechanisms are established, landowners and others learn about opportunities, technical advice is provided, rules for carbon accounting are developed and seedlings are made ava ilable. Focusing on achieving goals which go beyond just carbon sequestration, such as environmental and land management goals, is likely to be the most successful approach to afforestation over the longer term.

Reforestation is the planting of forests on lands which have, historically, previously contained forests but which have been converted to some other use. Two elements of regeneration strategies that could increase carbon sequestration potential are species selection and density management. While current research is aimed at maximizing the volumes of the commercial harvest, some results have shown that significant biomass gains can be achieved by modifying planting or spacing regimes. In addition to species selection and density management, increased planting instead of natural regeneration and seeding after harvesting can also increase carbon sequestration.

Another important climate change mitigation strategy to realize the potential of agricultural soil carbon sinks, including conservation practices on croplands (i.e., reduced or no tillage and reduced summerfallow), pasture management, conversion of marginal croplands to perennial grass and conservation of wetlands and riparian areas. Agricultural soil sequestration could offer crop producers greater revenue, and potentially lower input costs resulting from lower fuel use, as well as more efficient use of fertilizers. Encouragement of conservation practices on cropland, including no till and reduction in conventional summerfallow is potentially one of the more cost-effective strategies. The overall impact of agricultural soils conservation practices on the environment is a healthier, more productive soil that is less subject to wind or water erosion, and a more resilient, environmentally sustainable agro-ecosystem.

The restoration of wetland basins through re-establishment of aquatic vegetation, as well as soil carbon restoration in riparian zones and uplands that may be cultivated, is another important element of an integrated strategy to address climate change. Attributes of wetlands, which render them net sinks, include:

- high primary productivity ensuring abundant organic carbon available for sequestration,
- reduced decomposition due to the anaerobic nature of wetland sediments and colder northern climates,
- reduced CH4 emissions due to CH4 oxidation in the aerobic environment of algae and emergent vegetation,
- low nitrous oxide emissions due to continually water-logged soils and low nitrate levels in many wetlands.

The application of phytotechnologies in the management of forests, agricultural land and wetlands represents an important strategy for climate change mitigation and adaptation. However, the optimum use of phytotechnologies leading to the establishment of more resilient ecosystems requires a better understanding of the physiology of plant species under different environmental conditions, as well as an understanding of the role of plant biomass and biodiversity in relation to energy flows and ecohydrology.

F. Valuation of Ecological Services and Natural Capital

The term "ecological services" refers to the conditions and processes through which natural ecosystems sustain and fulfil human life. They are the result of complex natural cycles, driven by solar energy, which operate on different scales, influencing the workings of the biosphere in different ways. Ecological services are responsible for maintaining biodiversity and the production of ecosystem goods, such as food, timber, energy and natural fibre, as well as many pharmaceuticals, industrial products, and their precursors. The harvest and trade of these goods is based on “natural capital” and is an important part of the global economy. In addition to the production of goods, ecological services include life support functions, such as protecting watersheds, reducing erosion, providing habitats for wild species, as well as cleaning, recycling, and renewal. Some examples of the benefits of ecological services are:

- purification of air and water,

- mitigation of floods and droughts,
- detoxification and decomposition of wastes,
- generation and renewal of soil and soil fertility,
- pollination of crops and natural vegetation,
- dispersal of seeds and translocation of nutrients,
- control of agricultural pests,
- protection from the sun's harmful ultraviolet rays,
- moderation of temperature extremes and the force of winds and waves.

Plants are a fundamental part of the world's natural capital base due to the ecological services they provide. The application of phytotechnologies can increase the value of natural capital by augmenting the capacity of ecological systems to function effectively. Another fundamental issue is the inequitable distribution of costs and benefits associated with resource exploitation, resource conservation and biological diversity. While the benefits of biodiversity are widely dispersed, the costs of conservation are highly localized. Those nations with the least capacity for managing living resources are generally those richest in species. Tropical countries, for example, contain approximately two-thirds of all species and an even greater proportion of threatened species. Even though many of these nations recognize the need to safeguard threatened species they often lack the scientific skills, institutional capacities, and funds necessary for conservation.

People in the biodiversity rich areas of the world are usually dependent on the harvest of biological resources from a limited resource catchment area using their own labour. In economic terms, the value of the products extracted from the ecosystem may not be very large. Thus the non-use, preservation value of the ecosystem often provides a better option in realizing the real economic value of the ecosystem. However, although non-use values can be substantial, adequate mechanisms to quantify these values are lacking. This is because many of the services provided by ecosystems are external to conventional accounting systems and decision-making processes and are difficult to quantify. The flood control benefits, water filtration services, and species sustaining attributes of ecosystems are examples. As a result, the habitats that support complex ecosystems tend to be taken for granted, marginalized or valued too low in the absence of public intervention, since the inherent social and environmental benefits are usually only given limited consideration in the decision-making process. Public awareness of the real value of these ecosystem benefits is essential for the development and implementation of public policies for the protection of important habitats. This needs to be accompanied by a recognition of the distribution of the gains and losses, both across the current generation and between current and future generations in order to adequately ascertain the real value of ecological services and natural capital.

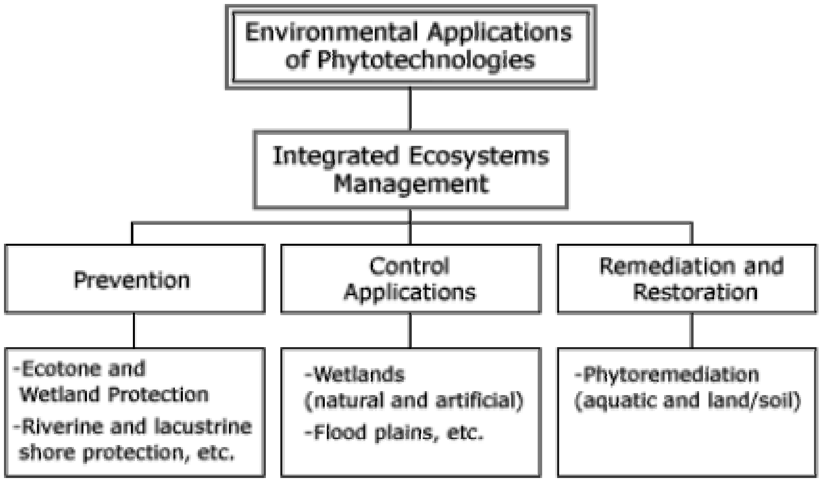
Depletion of natural resources can also be prevented by value addition. Many ecosystem products that form the basis of subsistence economies often leave the point of origin in an unprocessed state. As a result, the custodians of these resources usually realize very low value from the products that are extracted. Communities that are in full control of their own resource base tend to promote the sustainable stewardship of biological resources and the conservation of biodiversity. Such practices include limitations on harvest levels (e.g., number of sheep grazed on community pasture or wood harvested from community woodlots); lowering of harvesting pressures when there is evidence of over -harvesting (e.g., temporary bans on fishing); protection of species during vulnerable life stages (e.g., breeding birds); protection of certain key resources (e.g., trees); and the protection of certain biological communities (e.g., ponds and forests). These types of practices have evolved and persist because they serve the long term interests of key stakeholders at the local level in ensuring the availability of a diversity of sustainable resources.

Restoring the control and management of ecosystem resources to local communities may help maintain these ecosystems in better health and provide higher quality goods and services. This is because local people are most likely to possess the detailed spatial and temporal knowledge of the behaviour of the local ecosystems necessary for effective, adaptive management. Local people are also best situated to monitor human induced ecosystem impacts, and therefore to control them, provided they have the requisite authority and social structures in place to minimize wasteful exploitation of resources. Vesting local people with control over their own environments, and compensating them to maintain and restore biodiversity can be an effective way of taking good care of these valuable ecosystems. Management plans for ecological services must be adaptive, based on continual monitoring of resource abundance and extraction levels.

III. EXAMPLES OF ENVIRONMENTAL APPLICATIONS OF PHYTOTECHNOLOGY

Environmentally beneficial applications of phytotechnologies involve the use of plants to augment the capacity of ecosystems to absorb impacts; to prevent, reduce or remediate pollution; and to monitor and assess ecosystems health. These possible applications may also increase the functioning of ecological systems and hence the value of natural capital. For example phytotechnology applications might use plants to break down or sequester pollutants (sometimes making useful products along the way), or replace existing activities that pollute with ones that do not. Applications can also include the use of plants for water cycle and ecosystems restoration. Although the concept is not new, this area is evolving and novel applications are continuing to emerge. Table 5 summarizes some of the environmental applications of phytotechnologies reviewed in this section.

Table 5 Examples of Phytotechnology Applications



A. Ecotone Protection and Augmentation

Ecotones are transition areas between two adjacent ecological communities, for example, between aquatic and terrestrial ecosystems. Ecotones are crucial for protection of these ecosystems against anthropogenic impacts. The transition area has the same function for an aquatic ecosystem, such as a lake, as a membrane has for a cell. Essentially, the ecotone functions as a phytotechnology by preventing, to a certain extent, the penetration of undesirable contaminants into the lake and protecting the shoreline area.

- Non-point or diffuse pollutants in the environment inevitably flow toward surface water bodies, however the transition zone is usually able to transform and/or adsorb most pollutants entirely or partially, within a certain threshold. This can significantly reduce the potential for irreversible effects on the watershed as a whole. Ecotones serve not only as a buffer zone for protection against pollutants, but also as productive habitat for species present in adjacent ecosystems.
- During the past few decades, considerable damage has been done to the water/land ecotone due to the construction of concrete embankments for allowing natural currents to flow faster and for “protecting” shorelines from erosion. More recently, this practice has been changing to take advantage of the self purification capacity in freshwater bodies and rivers. The rehabilitation of the ecotone through the application of phytotechnologies has allowed vegetation to grow back naturally leading to improvements in water quality.

B. Natural Wetlands

Natural wetlands are important for maintaining aquatic ecosystem biodiversity and should be considered as part of an effective ecosystem management strategy. There are four major groups of natural wetlands:

- Fringe wetlands, which include salt marshes and lakeside marshes in which water typically flows in two opposite directions, influenced by lunar and/or storm tides,
- Riverine wetlands, which occupy floodplains, are usually characterised by water flowing in one direction,
- Depressional wetlands, such as prairie potholes, which usually receive much of their water from runoff and/or groundwater seepage rather than from surface water bodies, so that water residence times are longer,
- Peatlands also have long water residence times, but the accumulated peat creates a unique hydrologic regime that differs from the previous three types of wetlands.

Geomorphic setting, water source, and hydr odynamics generate considerable variation within each of these different categories of wetlands.

Water quality improvement is a positive service attributed to wetlands that absorb and recycle nutrients from human settlements. The denitrification potential of wetlands is often surprisingly high. As much as 2,000 to 3,000 kg of nitrate-nitrogen can be denitrified per hectare of wetlands per year, depending on the hydraulic conditions. This is important for the protection of surface waters because a significant amount of nitrate is released by agricultural activities. As much as 100 kg nitrate-nitrogen per hectare may be found in the drainage water from intensive agriculture. Since the denitrification is accompanied by the oxidation of organic matter, this process also removes a significant amount of organic matter.

Table 6 provides an overview of the different types and characteristics of wetlands are found adjacent to surface water bodies (i.e., wet meadows, freshwater marshes, forested wetlands, saltwater marshes, bogs, and shoreline wetlands). Their different abilities to cope with various non-point pollution problems are also summarized.

Table 6: Characteristics of Wetlands Adjacent to Lakes and Their Ability to Retain Non-Point Source Pollutants (UNEP/IETC, 1999)

Type of Wetland	Characteristics	Ability to Retain Non-Point SourcePollutants
Wet meadows	Grassland with waterlogged soil; standing water for part of the year	Denitrification only in standing water; removal of nitrogen and phosphorus by harvest.

Fresh water marshes	Reed-grass dominated, often with peat accumulation	High potential for denitrification, which is limited by the hydraulic conductivity
Forested wetlands	Dominated by trees, shrubs; standing water, but not always for the entire year	High potential for denitrification and accumulation of pollutants, provided that standing water is present
Salt water marshes	Herbaceous vegetation, usually with mineral soil	Medium potential for denitrification; harvest possible
Bogs	A peat-accumulating wetland with minor flows	High potential for denitrification but limited by small hydraulic conductivity
Shoreline wetlands	Littoral vegetation of significant importance for lakes and reservoirs	High potential for denitrification and accumulation of pollutants, but limited coverage

C. Constructed Wetlands

Recognition of the ability of wetlands to filter, absorb and metabolize suspended and dissolved matter has resulted in the fact that drainage of wetlands has ceased in many countries. In some cases, previously drained wetlands are now being restored. Furthermore, scientists and engineers are now working together to mimic these natural systems in order to contain and/or treat wastewaters and/or agricultural run-off. This has prompted the construction of artificial wetlands to cope with the diffuse pollution originating from agriculture, septic tanks, and other sources. In the U.S., for example, legislation prohibits the drainage of wetlands unless another wetland of the same size is constructed elsewhere.

Construction of artificial wetlands is an attractive and cost-effective phytotechnology that can be used for controlling pollution originating from diffuse sources and for treating various types of wastewater. For example, constructed wetlands can be used to treat dairy farm wastewaters, mine water pollutants, textile wastewater, and pulp mill wastewater. Wetlands are able to cope with the nitrogen and heavy metal pollution from these sources. However, it is essential to properly plan where to place the artificial wetlands, as their effectiveness is dependent on hydrology (i.e., they should be covered by water most of the year and have a sufficient retention time to allow them to treat specific pollutants), and topography (i.e., they should protect the most vulnerable ecosystems, which are often lakes and reservoirs). Furthermore, it is important to ensure that the wetlands themselves are not sources of potential pollutants, such as phosphorus.

Artificial wetlands are usually constructed so tha t water flows primarily over the sediment and through vegetation, or as vegetated submerged bed systems in which water flow is engineered for contact with plant roots. They are excavated with a shallow gradient in soils of low permeability (or lined with an impermeable barrier and then filled with an appropriate soil). They are then either planted or vegetated naturally. They usually comprise several cells that can operate in a series or in parallel, allowing flows to be redistributed for greater control and easier maintenance.

Nutrient retention and processing features that are characteristic of natural wetlands can be exploited in constructing wetlands. For instance, macrophytes can be kept in a rapid growth phase by intentional, programmed disturbances. Maintaining at least a moderate species diversity makes the system more responsive to variations in loading rates of different nutrients. Anaerobic conditions and large areas of vegetation-free sediment surface can maximize retention of both organic matter and nutrients. Manipulation of water turnover time and addition of other electron acceptors beside oxygen can also be performed in constructed wetlands. Linking constructed wetlands (where flows and vegetation can be controlled) with natural wetlands (for supplying soluble iron and aluminum needed for phosphorus removal) is a strategy for optimising the application of this environmentally sound approach to wastewater treatment.

Various emergent macrophyte species can be used in constructed wetlands, including cattails (*Typha spp*), bulrushes (*Scirpus spp*), reeds (*Phalaris spp*), rushes (*Juncus spp*), papyrus (*Cypersus spp*), and sedges (*Carex spp*). Submerged species can be applied in deep-water zones. Species that have been used for this purpose include coon tail or hornwort (*Ceratophyllum demersum*), redhead grass (*Potamogeton perfoliatus*), widegeon grass (*Ruppia maritima*), wild celery (*Vallisneria Americana*), and water milfoil (*Myriophyllum heterophyllum*). Artificial wetlands usually require two to four years to obtain sufficient plant coverage and biodiversity to be fully operational. Experience gained from the wetlands constructed to date suggests that the development and application of process models for the construction of artificial wetlands is essential if positive results are to be expected.

Constructed wetlands can serve the same small communities as natural wetlands and can be incorporated into the treatment systems for larger communities as well. Wetlands can also be constructed to treat agricultural runoff or other non-point sources of pollution and are especially well suited for use in surface-mined areas. Ancillary benefits, such as nitrogen and saltwater filtering, supply of water and nutrients, production of food and support of endangered species, can further increase the economic advantages compared to conventional wastewater treatment plants.

The self-purification ability of wetlands has found wide application as a wastewater treatment method in several developing countries such as China, Philippines, Burma, India, and Thailand. An integral part of this is the stocking of fish cultivated in biological sewage stabilization ponds. Through the intermediate activities of bacteria, algae, and other types of plankton, nutrients such as nitrogen and phosphorus are made available and metabolized by the fish.

D. Floating Macrophytes and Root Zone Plants for Improving Water Quality

Improving water quality through the use of floating macrophyte species is another phytotechnology application. For example, different types of duck weed and water hyacinths have been used as an alternative to waste stabilization ponds. The inorganic nitrogen and phosphorus contained in wastewater and decompos ed from organic pollutants by microorganisms are absorbed by the water hyacinths. The water hyacinths with microorganisms and organic materials attached or coagulated on root surfaces can then be harvested as feed for fish culture ponds and animal farms. However, use of water hyacinths requires strict control, as they can easily spread becoming a nuisance and also because they tend to incorporate and store heavy metals.

Root zone plants can also be effectively used for the treatment of small volumes of municipal wastewater, particularly where construction of a sewage collection system to an adjacent wastewater treatment facility would be prohibitively expensive. The decomposition of organic matter and denitrification usually do not cause any problem, provided that the plant is 5 to 10 square meters per person equivalent (depending on climatic conditions). The efficiency of phosphorus removal is usually no more than 10 to 20% for a root zone plant. However, this efficiency can be increased to 80% or more wit h the addition of iron chloride which allows the precipitation of iron phosphate. The application of this method appears to be attractive for recreational areas, where the density of population is low, but where wastewater loadings can have a significant impact.

E. Combined Waste Stabilisation Ponds and Wetlands

Combining the use of artificial wetlands with waste stabilization ponds and root zone plants is an attractive wastewater treatment method for developing countries, recreational areas adjacent to lake ecosystems, and areas with low population density. The reasons for this are:

- Wetlands can provide, through the use of filter media (i.e., sand, gravel or peat), a significant reduction of suspended matter from maturation pond effluent.
- Wetlands can buffer the pH value of the effluent from a waste stabilization pond.
- Effluents from waste stabilization ponds most often need a post treatment

polishing step and the use of wetlands offers an excellent cost-effective solution to this problem.

- The use of waste stabilization ponds and wetlands, in combination, offers a higher level of certainty as an effective pollution abatement and aquatic ecosystems management strategy.

F. Use of Plantations for Wastewater Treatment

Specialized, fast-growing plantations that require water and nutrients offer an efficient, inexpensive way to recycle wastewater. Trees absorb water for transpiration and metabolize the chemical constituents through timber biomass production. This has many advantages for some communities relative to other conventional methods of wastewater treatment. Tree plantations operate outside of the food chain, require little energy and have relatively low operating costs. However, additional health and safety measures are required for these open environment systems.

A plantation recycling system is composed of a forest plantation, a storage lagoon and a distribution network (i.e., pumps, pipes and sprinklers). It can be located at low cost on marginal agricultural land. To prevent groundwater contamination, this type of effluent recycling should be practised only during dry spells. When conditions are favourable, such as in sunny and/or windy weather, the recycling system should be loaded to its full capacity.

The process that determines the effectiveness of fast growing plantations for wastewater treatment is evapo-transpiration, which is largely dependent on weather. In temperate zones where this phytotechnology has been applied, hybrid poplars have been used because they quickly develop large foliage that stays on trees throughout the growing season. Due to advection, greatly enhanced by air circulation in a well-spaced plantation, this type of recycling system can achieve very high evapo-transpiration performance. Practical operational experience in applying this phytotechnology has enabled researchers to combine an innovative, environmentally sound effluent recycling system with intensive silviculture. This approach has considerable potential for recycling wastewater in crowded and growing cities in developing countries.

G. Use of Floodlands for Water Quality Improvement and Eutrophication Control

The application of ecohydrological principles for eutrophication and phosphorous control starts from the top of the catchment. The first stage involves the enhancement of nutrient retention within the catchment by reforestation, the creation of ecotone buffering zones, such as artificial flood lands, and the optimisation of agricultural practices. The buffering zones at the land water interface reduce the rate of groundwater flux due to evapotranspiration along the river valley gradient. Nutrient transformation into plant biomass in ecotone zones may further reduce the supply of nutrients into the river. The wetlands in the river valley buffering zone reduce the mineral sediments, organic matter and nutrient load transported by the river during floods periods through sedimentation. Also nitrogen load can be reduced significantly by regulation the water level to stimulate denitrification through anaerobic processes. The properties of large scale systems are difficult to predict and therefore should be assessed continuously at every stage of implementation and adjusted to maximise potential synergistic effects.

H. Phytoremediation

Phytoremediation is the term that refers to the use of plants for cleaning up contaminants in soil, groundwater, surface water and air. The use of phytoremediation can be a non-polluting and costeffective way to remove or stabilize toxic chemicals that might otherwise be leached out of the soil by rain to contaminate nearby watercourses. It is also a way of concentrating and harvesting valuable metals that are thinly dispersed in the ground, and offers an attractive option for the remediation of brownfield sites. Phytoremediation encompasses several methodologies, including:

- phytoextraction or phytoconcentration, where the contaminant is concentrated in the roots,stem and foliage of the plant,
- phytodegradation, where plant enzymes help catalyze breakdown of the contaminantmolecule,
- rhizosphere biodegradation, where plant roots release nutrients to microorganisms which are active in biodegradation of the contaminant molecule,
- volatilization, where transpiration of organics, selenium and mercury run through leaves of the plant,
- stabilization, where the plant converts the contaminant into a form which is not bioavailable, or the plant prevents the spreading of a contaminant plume.

The principal application of phytoremediation is for lightly contaminated soils, sludges and waters where the material to be treated is at a shallow or medium depth and the area to be treated is large, so that agronomic techniques are economical and applicable for both planting and harvesting. In addition, the site owner must be prepared to accept a longer remediation period.

Plants used to decontaminate soils must do one or more of the following:

- take up contaminants from soil particles and/or soil liquid into their roots,
- bind the contaminant into their root tissue, physically and/or chemically,
- transport the contaminant from their roots into growing shoots,
- prevent or inhibit the contaminant from leaching out of the soil.

The plants should not only accumulate, degrade or volatilize the contaminants, but should also grow quickly in a range of different conditions and lend themselves to easy harvesting. If the plants are left to die in situ, the contaminants will return to the soil. For complete removal of contaminants from an area, the plants must be cut and disposed of elsewhere in a nonpolluting way. Some examples of plants used in phyoremediation practices are water hyacinths (*Eichhornia crassipes*), poplar tress (*Papulus spp*), forage kochia (*Kochia spp*), alfalfa (*Medicago sativa*), Kentucky bluegrass (*Poa pratensis*), Scirpus spp, coontail (*Ceratophyllum demersvm L.*), American pondweed (*Potamogeton nodosus*) and the emergent common arrowhead (*Sagittaria latifolia*) amongst others.

Typically, researchers look for suitable phytoremediation properties among both cultivated and wild varieties of plants. If suitable wild species are not available, researchers can try to improve the effectiveness of phytoremediation by introducing different genetic varieties. One way this is done is by soaking seeds in a mutation-producing chemical, then screening the germinated seedlings for contaminant tolerance in artificial solutions containing various concentrations of the particular contaminant(s) of concern. Testing is carried out in batches of at least 50,000 seedlings at a time. The most tolerant and vigorously growing plants are analyzed for their contaminant content and the best of them are bred to produce a line of improved plants.

Although phytoremediation has not been used extensively, it has many advantages:

- It is low cost in comparison to current "mechanical" methods for soil remediation.
- It is passive and solar.
- It is faster than natural attenuation.
- The amount of contaminated material going to landfills can be greatly reduced.
- Energy can be recovered from the controlled combustion of the harvested biomass.
- It is low impact and public acceptance of phytoremediation is expected to be high.

A major barrier to the implementation of phytoremediation is that it is new and not fully developed. There is little regulatory experience with phytoremediation and it has to be considered on a site by site basis. Furthermore, the intrinsic characteristics of phytoremediation limit the size of the niche that it occupies in the site remediation market.

Some of the other limitations to phytoremediation are as follows:

- It is generally slower than most other treatment methods and is climate dependent.
- In most cases, the contamination to be treated must be shallow.
- It usually requires nutrient addition, and mass transfer is limited.
- High metal and other contaminant concentrations can be toxic to the plants, although some plants have greater adaptation to toxicity than others.
- Access to the site must be controlled, as the plants may be harmful to livestock and the general public.
- The contaminants being treated by phytoremediation may be transferre d across media (i.e., they may enter groundwater or may bioaccumulate in animals).
- For mixed contaminant sites (i.e., organic and inorganic) more than one phytoremediation methodology may be required.
- The site must be large enough to utilize agricultural machinery for planting and harvesting.

Momentum for the use of phytoremediation as a cleanup technique is building, particularly in application niches where other technologies are less suitable or do not exist. There will also likely be combined applications of bioremediation and phytoremediation. Table 7 illustrates how other remediation techniques compare to phytoremediation.

Table 7: Comparing Other Remediation Techniques to Phytoremediation

Treatment Name	Advantages Compared to Phytoremediation	Disadvantages Compared to Phytoremediation
Solidification / Stabilization	Not seasonally dependent; well established; rapid; applicable to most metals and organics; simple to operate during treatment.	Site is not restored to original form; leaching of the contaminant is a risk; can result in a significant volume increase.
Soil Flushing / Soil Washing	Not seasonally dependent, except in cold climates; methods well established for several types of sites and contamination.	Removal of metals using water flushing requires pH change;additional treatment steps and chemical handling add complexity and cost; possible lengthy period of treatment.

Bioremediation	Established and accepted; a bioreactor can be utilized for exsiting work; may be faster than phytoremediation.	Requires nutrient addition at a much greater level than phytoremediation; applicable to organics only.
Electrokinetics	Not seasonally dependent; can be used in conjunction with phytoremediation to enhance rhizosphere biodegradation.	Useful for soil only, not wetlands; uniformity of soil conditions is required.
Chemical Reduction / Oxidation	Not seasonally dependent; relatively short treatment time frame; usually off site.	Requires excavation; uses chemical additives; fertility of the soil after treatment may be damaged.
Excavation / Disposal	Rapid, immediate solution for site owner.	Transfers contaminants to landfill; does not treat.

I. Forestry and Agriculture

Forests are reservoirs of biodiversity. Preservation of their unique genetic characteristics is vital to the development of improved drugs, pesticides, foods and materials. To sustain renewable tree harvesting into the future, forest managers need to replace what they cut. Where forests have grown undisturbed for centuries, they are often impossible to replace. An important alternative therefore is to sustain the diversity of tree species through forest plantations. However, forest plantations can impact the environment through excessive use of chemical fertilizers, pesticides and herbicides. If in the long term they deplete the soil, these plantations become unsustainable. These potential impacts can be addressed in a number of ways, including:

- adding leguminous species to plantations to improve soil fertility and keep down weeds, reducing the need for both fertilizers and herbicides,
- leaving chipped logging residue and bark in the field to reduce nutrient loss and act as a mulch, which also decreases weed growth and the need for burning to prepare sites for subsequent plantings,
- using biological control against insect pests instead of using herbicides.

Climate also has a significant impact on the growth and viability of forests. A steady increase in average temperatures from global warming could dramatically alter today’s pattern of tree distribution, thereby putting certain species under stress and encouraging the spread of other species. In order to understand the adaptability of indigenous tree species to changes in climate, researchers in Finland are measuring the success of various tree species. They have established an arboretum and a gene pool forest with various species of conifers and hardwoods to maintain genetic diversity. The aim is to determine the factors that regulate tree characteristics, and to produce different varieties of seeds suitable for forest regeneration.

Agriculture is another important sector where phytotechnologies can be applied. The production and marketing of food and other farm products such as cotton and tobacco make up the world's largest single industrial sector. An important focus of crop research is to develop plants that are resistant to insect pests and diseases.

One of the lessons learned from the widespread spraying of pests is that simplistic approaches to controlling pests or diseases do not last. Insect pests, with their rapid rates of reproduction, can quickly evolve resistance to toxic sprays, while the buildup of the same poisons causes populations of their natural predators to decline. The result is a rebound of organisms that are much harder to get rid of.

Integrated pest management is an agricultural practice that combines reduced use of chemicals with alternative management strategies such as crop rotation, inter -cropping (i.e., growing two or more compatible crops in the same field), organic fertilisation, and control by natural predators. Genetic information, combined with the knowledge of how ecosystems function, is essential for the development and implementation of these alternative agricultural practices. By understanding the relationship between environmental factors, biodiversity and genetic characteristics, scientists are better able to advance this more sustainable, ecologically based approach to agriculture.

J. Bio-Energy

Biofuels, such as ethanol and methane are commonly produced from plants grown and harvested for this purpose and from waste plant biomass, including wood or agricultural residues. These sources of energy are renewable and relatively clean, and can be produced in most regions where pla nts can be grown.

Brazil, for example has produced fuel alcohol for years from fermented sugar cane. Fuel-making factories are built in areas where the cane is grown, minimizing the need for transport. Cane debris left behind after the fermentable juice is squeezed out is used as boiler fuel, supplying steam for stills, sterilization of equipment, and local electrical production. Since no other fuel is required for these operations, the fuel alcohol produced is a net gain.

The biggest part of the carbohydrate content in plants is not in the form of either starch or sugars but in cellulose – the material making up the structural cell walls of stems, leaves, hills, husks, cobs, etc. Lignocellulose (a mixture of cellulose, hemicellulose, and lignin) in wood and paper wastes makes a vast, cheap, widespread and largely untapped renewable source of biomass that can be converted to fuel. However, lignocellulose is very difficult to break down and convert into sugars and alcohol. The breakdown of cellulose alone re leases a mixture of sugars, including glucose, xylose, mannose, galactose and arabinose. Work is now being done to determine the best enzymes for rapidly and efficiently metabolize all of these sugars into ethanol With the right microbes feeding on the sugar residues found in waste paper and other biomass, significant quantities of ethanol could be produced each year.

IV. IMPORTANT CONSIDERATIONS FOR THE APPLICATION OF PHYTOTECHNOLOGIES

An understanding of the potential and limitations of phytotechnologies is crucial for their successful application. Limitations include insufficient knowledge and expertise regarding plant selection and the factors which influence plant growth, ecosystem interactions, and potential uses, as well as public and regulator y acceptance. Each application of phytotechnology involves site-specific considerations and should be evaluated on a case-by-case basis. The developers and proponents of phytotechnology systems must be able to demonstrate how phytotechnology will meet environmentalperformance objectives and minimize risk to both human and environmental health.

When phytotechnology applications are being considered, regulatory personnel, the public and stakeholders should be involved at the conceptualization stage. Regulators are responsible for testing, evaluating and reporting on the performance of technologies. The public and other stakeholders will gain confidence in the application of a given phytotechnology if they have access to data which demonstrates that it is appropriate for a given site. All concerned require demonstrated evidence that phytotechnologies will meet performance expectations and regulatory standards with minimal risk to human health and the environment.

To determine if a particular phytotechnology application is appropriate, the following criteria should be considered and evaluated by regulatory personnel, site owners and stakeholders:

- **Overall protection of human health and the environment** – It is essential to determinewhether the phytotechnology eliminates, reduces or controls threats to public health andthe environment.
- **Compliance with regulatory requirements** – This is important to ensure that theproposed phytotechnology application meets environmental statutes, regulations, andother requirements that pertain to the site.
- **Long term effectiveness** – This must consider the ability of the phytotechnology toprotect, human health and the environment over time and the reliability of such protection,including the degree of certainty that its application will prove successful.
- **Short term effectiveness** – This should consider the length of time needed to implementthe phytotechnology and the risks it may pose to workers, residents and the environmentduring implementation.
- **Implementability** – This should consider the technical and administrative feasibility ofimplementing the phytotechnology, and its practicality, the requirements forimplementation, and the availability of goods and services that may be needed.
- **Cost** – It is necessary to take into account the overall capital costs, as well as the ongoing operation and maintenance costs.
- **Government and community acceptance** – This involves the determination of the overall acceptability of the studies and evaluations that are undertaken, as well as the necessary approvals for the phytotechnology application to proceed.

The application of phytotechnology involves more than going to a site and planting seedlings, grass or some other type of plant. Phytotechnology is an in situ approach that requires careful cons ideration of site-specific characteristics. A checklist should be used to plan and review the effectiveness of the technology, thereby providing the site owners, technology proponents, designers, regulators, and other stakeholders with a common set of data requirements and expectations. The checklist should include:

- Site visit
- Baseline site characterization and review of site characterization data, including an agronomic assessment of the site
- Determination of the environmental objectives for the site and how the phytotechnology will achieve environmental goals

- Project expectations of the site owner, regulators, stakeholders, and the public, including the identification of stakeholder and public concerns
- Experience and expertise of the phytotechnology design team
- Proposed phytotechnology system design and estimated time to undertake the project
- Feasibility studies for plant selection using laboratory tests and greenhouse studies
- Operations and maintenance plan
- Plan to deal with any secondary wastes (i.e., contaminated plants) that may be generated
- Overall monitoring plan
- Contingency plan.

A. Site Characterization

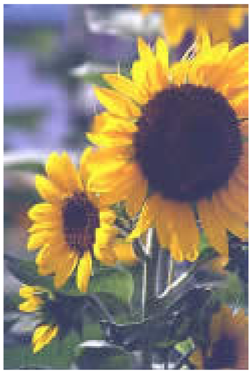
A complete site characterization is essential for the application of phytotechnologies. Characterization should include an evaluation of surface features, structures and buried services to determine whether the site is amenable to a phytotechnology application. Site characterization should provide data on the following:

- Site description
- Geological data
- Hydrogeologic data
- Aquifer characteristics
- Soil conditions
- Air quality
- Climatic conditions
- Geochemical data
- Microbiology
- Presence and distribution of contaminants (if any)
- Risk assessment.

Assessment of available data should include an analysis of the sufficiency and validity of the data in relation to the proposed phytotechnology application.

As part of the site characterization, agronomic studies should be conducted to determine if site conditions will support plant growth. Soil samples should be collected and analyzed for soil parameters influencin g plant growth, including soil pH, soil fertility and nutrient content, soil structure, soil texture, soil temperature, and soil depth. Saline groundwater conditions may adversely affect plant growth of some species of plants. The site soils should be amended as necessary to optimize plant growing conditions. The need for an irrigation system should also be determined.

B. Plant Selection



Native, non-agricultural plants are generally preferred for phytotechnology applications. In most applications, plants that are adapted to local conditions will have better chances of success than non-adapted plants. The use of mixed species of vegetation can also lead to greater chances of success than the use of monocultures. Care should be taken not to introduce specie s of plants that are invasive or a nuisance. In cases where the spread of a plant is undesirable, the plants should be selected to prevent reproduction.

The long term establishment of vegetation at a site is dependent on the project goals and the future intended use of the site. For phytotechnology applications involving little or no maintenance at a given site, it is likely that there will be a succession of plants. If so, this succession could be planned when considering types and timing of vegetation. Plant rotation could be important when short-lived vegetation is used that does not meet overall objectives or for vegetation that should not be replanted in the same place.

C. Modelling

Models are essentially a simplified picture of reality that can be used to help solve problems. The use of modelling in the environmental field has developed rapidly during the last two decades due to:

- The development of computer technology, which can handle very complex mathematical systems,
- A better understanding of pollution problems, including the recognition that complete elimination of pollution (or "zero discharge") is not feasible, but that proper pollution control within the limitations of available financial resources requires serious consideration of the potential impacts of pollution on ecosystems,
- Increasing knowledge regarding the quantitative relationships in ecosystems, and between the various ecological properties and environmental factors.

Ecosystem models can be considered a synthesis of what we know about the ecosystem, or a component of the ecosystem, with reference to a given problem. It is therefore not surprising that ecological models have been used increasingly as a tool to understand the properties of the ecosystem. The principal advantages of models are that they can be used to survey complex systems, reveal system properties and gaps in our knowledge, and help establish research priorities. Models are useful in tests of scientific hypotheses because they can simulate real conditions, which can then be compared with actual observations.

Modelling may be necessary to optimize the phytotechnology application or to predict behavior. For example, plant uptake models may be used to predict the rate at which a contaminant will be degraded within a plant. Similarly, ecosystem models can be used to understand the relationships between the physical and biological components of phytotechnologies as part of the overall ecosystem.

D. Operations and Maintenance

An operations and maintenance plan will ensure optimal performance of the phytotechnology application. The level of detail in an operations and maintenance plan is a function of the type of phytotechnology being use. For example, a more detailed operation and maintenance plan would likely be required for wetland operations than for a riparian buffer.

The operation and maintenance plan should address a wide variety of requirements. An irrigation system may be needed to start plants or to keep them growing. Soil conditions should be monitored for pH, fertilizer requirements, and needed soil amendments. The site may need fencing to keep out people and animals. The site maintenance plan should address pruning, thinning, mowing, weed control and litter removal.

Table 8 lists some of the parameters that should be part of an operations and maintenance plan for phytotechnology applications.

Table 8: Operations and Maintenance Requirements for Phytotechnologies

Operations Parameter	Maintenance Requirement
Soil conditions	Maintain soil amendments, soil pH, and fertilizer requirements
Irrigation system	Irrigation system may be needed to start plants and may be needed during drought conditions
Plant maintenance	Plants may need to be thinned, pruned, mowed and treated to control weeds

Fencing	Fencing may need to be installed to keep people and animals out. Fencing is an important safety factor when wetlands are used.
Replanting	Replanting will be required for annual plants. Replanting trees will be required if they are damaged or fail to grow.
Vector control	Phytotechnology applications attract mice, rats, starlings and other vectors that may be a nuisance. A suitable control plan will be needed.
Monitoring well maintenance	Monitoring wells will be needed and they require some maintenance.
Disposal of plant waste	Plant waste will need to be collected and disposed of properly. For some phytoremediation applications, plant waste may need to be treated as a hazardous waste.
Stormwater runoff	Best management practices should be used to control stormwater runoff from the site
Mechanical support systems	Maintenance will be required for mechanical systems
Wetlands systems	Pond maintenance, plant harvesting, influent and effluent monitoring, and sediment control will be required.

E. Monitoring

The monitoring plan for a phytotechnology site needs to address environmental quality objectives and use established sampling protocols. Monitoring of groundwater, soil, sediment, plants, air and surface water at the site will initially be required. The monitoring plan must address basic issues affecting plant health including soil nutrients, soil pH, soil microbial activity and tree sap flow monitoring. Water monitoring at a site where a phytotechnology is being applied should include soil water, groundwater, surface water, runoff and effluent (from a wetland). The frequency and types of water tests will be site-specific, depending upon site conditions.

The monitoring plan should be designed to collect data to optimize the phytotechnology system, monitor the adverse impacts to the ecosystem, and measure progress in meeting overall objectives. The monitoring plan should therefore contain the following basic elements:

- Constituents, parameters, or items to be monitored,
- Frequency and duration of monitoring,
- Monitoring/sampling methods,
- Monitoring locations,
- Analytical methods,
- Quality assurance/ quality control (QA/QC) requirements.

F. Contingency Planning

One of the important considerations in applying the phytotechnology system is the need to prepare a contingency plan in case the intended phytotechnology application does not meet environmental goals. The plan should cover a wide range of possible failure mechanisms (drought, floods, disease, animals). It may take several years of monitoring to determine that the phytotechnology is not meeting performance expectations. Each contingency plan will be site-specific, depending upon numerous factors, including:

- Regulatory requirements,
- Funding,
- Type of phytotechnology application,
- Site environmental conditions (growing season, amount of rain, etc.),
- Time required to meet specified environmental objectives.

If the phytotechnology application is not achieving the expected goals, the site owner, regulator and stakeholders should consider implementation of the contingency plan.

G. Expertise

The development and implementation of phytotechnologies requires a multi-disciplinary team. The team should include personnel with expertise and experience in the following disciplines:

- **Soil Scientist/ Agronomist** – to evaluate the ability of the soil conditions to support plants that can function in a manner which will address objectives and expectations,
- **Plant Biologist/Botanist** – to evaluate the range of plants that might be applicable and to conduct greenhouse tests using soil and water samples

from the site to ensure the plants will grow successfully,

- **Hydrologist** – to undertake groundwater modelling, including modelling on the fate and transport of any contaminants of concern,
- **Regulatory Specialist** – to determine the requirements for sampling, analysis, maintenance and monitoring,
- **Environmental Engineer** – to undertake the overall phytotechnology system design and to ensure all project costs are captured,
- **Risk Assessor/ Toxicologist** – to evaluate the risk of the proposed phytotechnology application in relation to alternatives,
- **Ecologist/Ecosystem Modeller** – to ascertain the relationships between the plants and their environment as well as the ecosystem itself in order to forecast changes in ecosystems and related processes

V. KEY ISSUES AND FUTURE ACTIONS

Issues and concerns about the application and use of phytotechnologies range from effects on the environment and human health to impacts on social and economic conditions. Some of these issues arise specifically from the nature of technology, while others, such as resource exploitation, are part of the ongoing dilemma of population growth and the impact of human activities in relation to sustainable development.

Some key questions related to the **environmental, health and safety** aspects of phytotechnology applications are:

- How can natural systems be used effectively to improve environmental quality?
- How can more ecologically sound technologies such as phytotechnologies be used incomplementary ways to enhance the functioning and effectiveness of natural systems?
- How can biodiversity be protected?
- Will genetically altered plants upset the balance of natural ecosystems?
- Are current regulations adequate?

With respect to **socio-economic issues** key questions are:

- How can ecologically sound engineering and related ecotechnologies, such as phytotechnologies, be further developed, promoted and applied in beneficial ways?
- How can the cost effectiveness of phytotechnology applications be improved?
- How can "natural capital" and the benefits of ecosystem services be better quantified to help justify environmentally sound practices?

- What needs to be done to ensure that developing countries realize the benefits of biodiversity (including plant biodiversity) and the responsible stewardship of their genetic resources?
- How can stakeholders be engaged more effectively in the process of addressing issues and concerns and developing appropriate solutions?
- How can information on phytotechnologies be managed and made more accessible?

The effectiveness of phytotechnology applications depends on having both broad-based and expert input into their development, adoption and ongoing monitoring. Governments, the private sector and citizens must all be involved, and systems for collecting, synthesizing and feeding back information and knowledge on phytotechnologies must be established and maintained. Issues and concerns must be addressed in a transparent, credible manner, and proactive strategies are required to ensure responsible action.

An ecological approach to development is often difficult to achieve because the task of synthesis is usually inadequately understood or cultivated in the practice of contemporary science, politics or public administration, and the science of ecology (potentially the most complex of all sciences) is itself underdeveloped. In promoting the adoption and use of environmentally sound technologies such as phytotechnology, two strategies for change are required – a short term, intermediate and adaptive strategy to cope with basic realities and conditions as they are; and a long term, reconstructive strategy to establish comprehensive goals for sustainable development and plans for their attainment. The thesis behind this is the need to prevent the foreclosure of future possibilities that might otherwise occur because of present, high risk, irreversible decisions. Better policies and procedures are urgently required to reduce the extent of damage to the biosphere until more adequate ecologically sound approaches can be provided. Proactive strategies involving stakeholders are therefore required in four crucial areas:

- Awareness raising
- Transparency and accountability
- Effective regulations
- Science and technology.

A. Awareness Raising

It is important to facilitate access to information and to develop and apply environmentally sound technologies, such as phytotechnology, in an appropriate manner. Actions to educate stakeholders and establish integrated databases and information networks should be targeted. Emphasis should be given to establishing ecosystem objectives and protecting ecosystem integrity, implementing appropriate management options. Two-way information flow is essential, recognising the particular needs of developed and developing countries and the contributions each can make to achieving environmentally sustainable objectives by protecting biodiversity and promoting the appropriate use of phytotechnologies.

B. Transparency and Accountability

Policy-makers should ensure development and implementation of resource-conserving practices and environmentally sound technologies, such as phytotechnologies, which support biodiversity and ecosystem integrity. Decision-making and policy processes should be transparent, taking into account basic requirements, as well as the value of "natural capital". Strategies for self-reliance and debt avoidance should be encouraged. Emphasis should be given to full disclosure and transparent reporting of options and progress in meeting sustainable development objectives.

C. Effective Regulations

Governments are responsible for enforcement and compliance with environmental standards and regulations. Their challenge includes implementing interdisciplinary approaches for measuring exposure risks, ranking sources of environmental contamination and ecosystems degradation, assessing impacts, modelling cause-and-effect relationships, analysing costs and benefits of risk reduction, and implementing appropriate prevention and control measures. Policy actions should support full accounting of economic and environmental costs, as well as the consistent and fair application of environmental regulations within a framework that supports the development of innovative, ecosystem -based solutions, such as those which can be achieved through the appropriate use of phytotechnologies.

D. Integrating Science and Technology

When policy-makers look to science and technology, it is important that they recognize how complicated it is to acquire and sustainable, environmentally sound technologies. Research should be directed towards the development of sustainable solutions which take into account ecosystem needs. Technology decisions should consider overall life-cycle costs, benefits and risks, the mix of human and capital resources required, and the conditions where environmentally sound technologies such as phytotechnologies may be applied.

If the determination of priorities is to reflect sound judgement, a precondition must be the identification of crit ical ecological factors. Better means of measuring and forecasting ecological changes are certainly needed, as are ecological monitoring and observation techniques to identify what should not be done. Avoiding unnecessary foreclosure of future opportunity and avoiding unwanted irreversible effects is often a more appropriate outcome than the formulation of comprehensive ecologically oriented programs that may not be operationally viable.

The UNEP - DTIE International Environmental Technology Centre

Established in April 1994, the International Environmental Technology Centre (IETC) is an integral part of the Division of Technology, Industry and Economics (DTIE) of the United Nations Environment Programme (UNEP). It has offices at two locations in Japan - Osaka and Shiga.

The Centre's main function is to promote the application of Environmentally Sound Technologies (ESTs) in developing countries and countries with economies in transition. IETC pays specific attention to urban problems, such as sewage, air pollution, solid waste, noise, and to the management of fresh water basins.

IETC is supported in its operations by two Japanese foundations: The Global Environment Centre Foundation (GEC), which is based in Osaka and handles urban environmental problems; and the International Lake Environment Committee Foundation (ILEC), which is located in Shiga Prefecture and contributes accumulated knowledge on sustainable management of fresh water resources.

IETC's mandate is based on Agenda 21, which came out of the UNCED process. Consequently IETC pursues a result-oriented work plan revolving around three issues, namely: (1) Improving access to information on ESTs; (2) Fostering technology cooperation, partnerships, adoption and use of ESTs; and (3) Building endogenous capacity.

IETC has secured specific results that have established it as a Centre of Excellence in its areas of speciality. Its products include: an overview on existing information sources for ESTs; a database of information on ESTs; a regular newsletter, a te chnical publication series and other media materials creating public awareness and disseminating information on ESTs; Local Agenda 21 documents developed for selected cities in collaboration with the UNCHS (Habitat)/UNEP Sustainable Cities Programme (SCP); advisory services; Action Plans for sustainable management of selected lake/reservoir basins; training needs assessment surveys in the field of decision-making on technology transfer and management of ESTs; design and implementation of pilot training programmes for adoption, application and operation of ESTs; training materials for technology management of large cities and fresh water basins; and others.

The Centre coordinates its activities with substantive organisations within the UN system. IETC also seeks partnerships with international and bilateral finance institutions, technical assistance organisations, the private, academic and non-governmental sectors, foundations and corporations.

UNEP Division of Technology, Industry and Economics

The mission of the UNEP Division of Technology, Industry and Economics is to help decision-makers in government, local authorities, and industry develop and adopt policies and practices that: - are cleaner and safer; - make efficient use of natural resources; - ensure adequate management of chemicals; - incorporate environmental costs; - reduce pollution and risks for humans and the environment.

The UNEP Division of Technology, Industry and Economics (UNEP DTIE), with the Division Office in Paris, is composed of one centre and five branches:

The International Environmental Technology Centre (Osaka), which promotes the adoption and use of environmentally sound technologies with a focus on the environmental management of cities and freshwater basins, in developing countries and countries in transition.

Production and Consumption (Paris), which fosters the development of cleaner and safer production and consumption patterns that lead to increased efficiency in the use of natural resources and reductions in pollution.

Chemicals (Geneva), which promotes sustainable development by catalysing global actions and building national capacities for the sound management of chemicals and the improvement of chemical safety world-wide, with a priority on Persistent Organic Pollutants (POPs) and Prior Informed Consent (PIC, jointly with FAO).

Energy and OzonAction (Paris), which supports the phase-out of ozone depleting substances in developing countries and countries with economies in transition, and promotes good management practices and use of energy, with a focus on atmospheric impacts. The UNEP/RISØ Collaborating Centre on Energy and Environment supports the work of the Unit. Economics and Trade (Geneva) , which promotes the use and application of assessment and incentive tools for environmental policy and helps improve the understanding of linkages between trade and environment and the role of financial institutions in promoting sustainable development.

Coordination of Regional Activities Branch, which coordinates regional delivery of UNEP DTIE's activities and ensures coordination of DTIE's activities funded by the Global Environment Facility (GEF).

UNEP DTIE activities focus on raising awareness, improving the transfer of information, building capacity, fostering technology cooperation, partnerships and transfer, improving understanding of environmental impacts of trade issues, promoting integration of environmental considerations into economic policies, and catalysing global chemical safety. For more information contact:

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GLOSSARY

agrochemicals	pesticides and fertilizers developed artificially for agricultural use
algae	small, often microscopic, aquatic plants in a water body
aquaculture	artificial cultivation or growth of fish, crayfish and other organisms for use as food, particularly in fishpondsand similar structures
aquatic environment	the combination of physical, chemical, and biological conditions present in lakes, reservoirs, wetlands, rivers and oceans
bacteria	one of the five kingdoms of living beings. Bacteria are structurally simple single cells with no nucleus.
basin	a water catchment area, including rivers, streams, lakes, estuaries, etc.
bio	life, of living beings, biological
biocatalyst	a substance, such as an enzyme or hormone that activates or speeds up a biochemical reaction
biocenosis	a community of biologically integrated and interdependent plants and animals
biochemistry	the branch of chemistry that deals with plant and animals and their life processes
biocide	a poisonous chemical substance that can kill living organisms
bioclimatology	the science that deals with the effects of climate on living matter
biodegradeable	capable of being decomposed by biological means
biodiversity	variability among living organisms and the ecosystems of which they are a part
bioecology	the science that deals with the interrelations of communities of animals and plants with their environment
bioengineering	the application of engineering science and technology to problems of biology and medicine
biogechemical cycle	the cycle in which nitrogen, carbon and other inorganic elements of the soil, water and atmosphere are converted into the organic composition of animals and plants and then released back into the environment
biogeography	the branch of biology that deals with the geographical distribution of plants and animals
biology	the science that deals with the origin, history, physical characteristics and life processes of plants and animals
bioluminescence	the production of light by living organisms
biomanipulation	the use of native or artificially introduced biological organisms to treat eutrophication

biomass	the total mass or amount of living organisms in a particular area or volume
biome	an extensive community of plants and animals whose makeup is determined by soil and climatic conditions
biomedicine	a branch of medicine that is combined with research in biology
bioremediation	the use of living organisms to treat contaminants or remediate contaminated soil, water or air
bioscience	any science whose systematized knowledge is applied to the functions or problems of living organisms
biosphere	the zone of the earth, extending from its crust out into the surrounding atmosphere, which contains living organisms
biosynthesis	the formation of chemical compounds by the cells of living organisms
biota	plant and animal life
biotechnology	the application of science and engineering to study problems and provide solutions involving living beings
biotreatment	the use of living organisms to t reat contaminants
buffering	capacity a measure of the ability of a system to meet changes imposed from the environment
constructed wetlands	artificial or engineered wetlands used to remediate surface water or waste water
Eco	of the environment, habitat
eco-engineering	the application of science and technology to problems involving living organisms and their environment
ecohydrology	the integrated study of ecosystems and hydrological processes and their combined potential to influence water dynamics and quality, particularly at the catchment scale
ecology	the branch of biology that deals with the relationship between living organisms and their environment
ecosystem	a system made up of a community of animals, plants and bacteria, and the physical and chemical environment
ecosystem restoration	the process of intentionally altering a site to establish a defined, indigenous ecosystem. The goal of this process is to emulate the structure, function, diversity and dynamics of the specified ecosystem.
ecotechnology	the application of science and engineering to study problems and provide solutions involving ecosystems
ecotone	a transitional zone between two adjacent communities containing species characteristic of both as well as other species occurr ing

only within the zone.

ecotype a group of physiological or morphological variants within a biological species adapted to particular environmental conditions

environmental engineering the application of science and technology to environmental problems

euphotic zone the upper portion of a lake or reservoir where sufficient light is present to support growth of aquatic plants

eutrophic lake or water reservoir a water body receiving large amounts of nutrients from its watershed. It is characterized by high photosynthetic activity and low water transparency.

forensic ecology investigation of a site to determine the history and causes of the current flora and fauna

gene the physical unit of inheritance, made up of a particular sequence of nucleotides on a particular site on a particular chromosome.

gene expression the conversion of the gene's nucleotide sequence into an actual process or structure in the cell. Some genes are expressed only at certain times during an organism's life and not at others.

genetically modified organisms (GMOs) the product of biotechnology, which enables genes and their properties to be transferred from one organism, unconstrained by natural reproductive barriers.

genome all the genes in a complete set of chromosomes

hydrodynamics the branch of physics which pertains to the motion and action of water and other liquids

hydrology the science dealing with the waters of the earth, their distribution on the surface and underground, and the cycle involving evaporation, precipitation and flows

impoundments man-made lakes, usually created by the construction of a dam across a river channel; in contrast to natural lakes, impoundments exist because they were constructed for a specific purpose or water use

integrated pest management (IPM) the use of combined strategies to combat pests, including chemical, physical, and biological methods of control

limnology the study of lakes, reservoirs, wetlands and rivers, including their physical, chemical and biological aspects

littoral zone water in a lake or reservoir that is closest to the shore

macrophytes macroscopic (polycellular) plants which can either be submerged (i.e., completely covered by water) or emergent (i.e., only partly covered by water). A distinction can also be made between rooted plants, which have their roots in the sediment, and floating plants, which are floating on the water surface.

mesotrophic lake or a water body receiving moderate amounts of nutrients from its

water reservoir watershed. Phytoplankton and other aquatic organisms are not numerous.

micropropagation the mass production of plants from small amounts of cells or tissue

nitrification the process where ammonium is converted to nitrate nucleotides a compound consisting of a base, a phosphate group, and a sugar. DNA and RNA are linear chains (polymers) of nucleotides

oligotrophic lake or water reservoir a water body receiving a relatively small amount of nutrients from the watershed. The biomass of the phytoplankton is not high, nor is the quantity of other aquatic organisms

organic matter any molecules containing carbon produced by plants, animals and humans

photosynthesis the process by which plants and some bacteria use energy from light to form organic matter from inorganic substrates

phyto plant, flora, vegetation

phytoaccumulation like phytoextraction, refers to the uptake and translocation of contaminants in soil by plant roots into the other parts of the plant

phytodegradation like phytotransformation, refers to the breakdown of contaminants taken up by plants through metabolic processes within the plant, or the breakdown of contaminants external to the plant through the effect of compounds (such as enzymes) produced by the plants.

phytoextraction like phytoaccumulation, refers to the uptake and translocation of contaminants in soil by plant roots into the other parts of the plant

phytofortification the fortification of plants with essential nutrients, vitamins and metabolites during their growth and development, there by making these additives more readily available for human/animal consumption

phytogenesis the science of the origin and development of plants

phytogeography the geography of the distribution of plant life

phytohormone plant hormone

phytohydraulics the use of plants to rapidly uptake large volumes of water to contain or control the migration of subsurface water

phytopathology the study of plant diseases and their control

phytopharmaceuticals medicinal preparations obtained from plants

phytoplankton the community of predominantly single cell plants inhabiting the water mass

phytoremediation the use of plants to treat contaminants or remediate contaminated soil, water or air

phytostabilization the use of certain plant species to immobilize contaminants in the soil and groundwater through absorption and accumulation by roots, adsorption onto roots, or precipitation within the root zone of plants.

phytotechnology the application of science and engineering to study problems and provide solutions involving plants

phytotoxic toxic to plants

phytotransformation like phytodegradation, refers to the breakdown of contaminants taken up by plants through metabolic processes within the plant, or the breakdown of contaminants external to the plant through the effect of compounds (such as enzymes) produced by the plants.

phytovolatilization the uptake and transpiration of a contaminant by a plant, with release of the contaminant or a modified form of the contaminant to the atmosphere from the plant.

recombinant DNA novel DNA made by joining DNA fragments from different sources

recuperation the act or process of regaining or restoring stability or balance

remediation the act or process of overcoming problems or deficiencies

restoration the act or process of bringing something back to its original condition

rhizofiltration the adsorption or precipitation of contaminants in solution onto plant roots. It also refers to the absorption of contaminants into the roots.

riparian corridor the corridor along the bank or shore of a body of water sediments materials in a lake or reservoir which are either suspended in the water column or deposited on the bottom. They usually consist of the remains of aquatic organisms, precipitated minerals and eroded material from the watershed.

transgenic organism an organism into which the genes of other species have been engineered

treatment the act, manner, or method of addressing or dealing with something

vegetative cover a long term, sustaining cap composed of soil and plants growing in and/or over waste such as mine tailings, or in a landfill

watershed the area drained by a river or river system

wetland the aquatic habitat in which plants, in contrast to microalgae, are predominant. This includes swamps, marshes, bogs and shallow lakes.

zooplankton a community of invertebrate organisms inhabiting the water mass, usually feeding on bacteria, phytoplankton and/or detritus.