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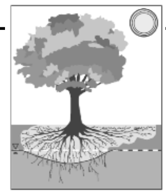
# Welcome – Thanks for joining us.
## ITRC's Internet-based Training Program

# **Phytotechnologies**



Phytotechnology Technical and Regulatory Guidance and Decision Trees, Revised (Phyto-3, 2009)

Sponsored by: Interstate Technology and Regulatory Council (www.itrcweb.org)
Hosted by: US EPA Clean Up Information Network (www.cluin.org)

Phytotechnologies is a set of technologies using plants to remediate or contain contaminants in soil, groundwater, surface water, or sediments. These technologies have become attractive alternatives to conventional cleanup technologies due to relatively low capital costs and the inherently aesthetic nature of planted sites.

This training familiarizes participants with ITRC's Phytotechnology Technical and Regulatory Guidance and Decision Trees, Revised (Phyto-3, 2009). This document provides guidance for regulators who evaluate and make informed decisions on phytotechnology work plans and practitioners who have to evaluate any number of remedial alternatives at a given site. This document updates and replaces Phytoremediation Decision Tree (Phyto-1, 1999) and Phytotechnology Technical and Regulatory Guidance Document (Phyto-2, 2001). It has merged the concepts of both documents into a single document. This guidance includes new, and more importantly, practical information on the process and protocol for selecting and applying various phytotechnologies as remedial alternatives.

This guidance contains decision trees:

Remedy Selection Decision Tree

Groundwater Decision Tree

Soil/Sediment Decision Tree

Riparian Zone Decision Tree

This course will be most useful to you if you download the guidance and follow the discussion with the Decision Trees displayed in your guidance. Our instruction is how to use the Guidance – not how to use the decision trees process. That is explained within the Guidance.

ITRC (Interstate Technology and Regulatory Council) www.itrcweb.org

Hosted by: US EPA Technology Innovation and Field Services Division (TIFSD) (www.clu-in.org)

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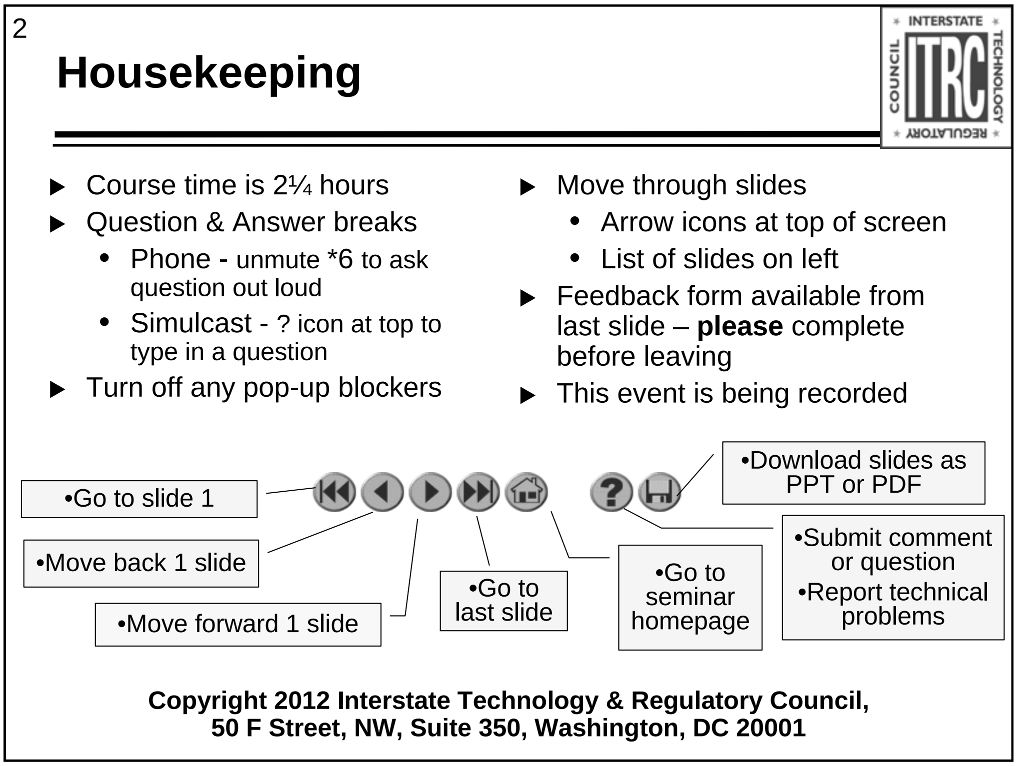


Although I'm sure that some of you are familiar with these rules from previous CLU-IN events, let's run through them quickly for our new participants.

We have started the seminar with all phone lines muted to prevent background noise. Please keep your phone lines muted during the seminar to minimize disruption and background noise. During the question and answer break, press *6 to unmute your lines to ask a question (note: *6 to mute again). Also, please do NOT put this call on hold as this may bring unwanted background music over the lines and interrupt the seminar.

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## ITRC (www.itrcweb.org) – Shaping the Future of Regulatory Acceptance

- Host organization
- Network
  - State regulators
    - All 50 states, PR, DC
  - Federal partners

    •DOE •DOD •EPA
  - ITRC Industry Affiliates Program
  - Academia
  - Community stakeholders
- Wide variety of topics
  - Technologies
  - Approaches
  - Contaminants
  - Sites
- Products
  - Technical and regulatory guidance documents
  - Internet-based and classroom training

The Interstate Technology and Regulatory Council (ITRC) is a state-led coalition of regulators, industry experts, citizen stakeholders, academia and federal partners that work to achieve regulatory acceptance of environmental technologies and innovative approaches. ITRC consists of all 50 states (and Puerto Rico and the District of Columbia) that work to break down barriers and reduce compliance costs, making it easier to use new technologies and helping states maximize resources. ITRC brings together a diverse mix of environmental experts and stakeholders from both the public and private sectors to broaden and deepen technical knowledge and advance the regulatory acceptance of environmental technologies. Together, we're building the environmental community's ability to expedite quality decision making while protecting human health and the environment. With our network of organizations and individuals throughout the environmental community, ITRC is a unique catalyst for dialogue between regulators and the regulated community.

For a state to be a member of ITRC their environmental agency must designate a State Point of Contact. To find out who your State POC is check out the "contacts" section at www.itrcweb.org. Also, click on "membership" to learn how you can become a member of an ITRC Technical Team.

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# ITRC Course Topics Planned for 2012 – More information at www.itrcweb.org

•**Popular courses from 2011**

- **Bioavailability Considerations for Contaminated Sediment Sites**
- **Biofuels: Release Prevention, Environmental Behavior, and Remediation**
- **Decision Framework for Applying Attenuation Processes to Metals and Radionuclides**
- **Development of Performance Specifications for Solidification/Stabilization**
- **LNAPL 1: An Improved Understanding of LNAPL Behavior in the Subsurface**
- **LNAPL 2: LNAPL Characterization and Recoverability - Improved Analysis**
- **LNAPL 3: Evaluating LNAPL Remedial Technologies for Achieving Project Goals**
- **Mine Waste Treatment Technology Selection**
- **Phytotechnologies**
- **Permeable Reactive Barrier (PRB): Technology Update**
- **Project Risk Management for Site Remediation**
- **Use and Measurement of Mass Flux and Mass Discharge**
- **Use of Risk Assessment in Management of Contaminated Sites**

•**New in 2012**

- **Green & Sustainable Remediation**
- **Incremental Sampling Methodology**
- **Integrated DNAPL Site Strategy**

**2-Day Classroom Training:**

- **Light Nonaqueous-Phase Liquids (LNAPLs): Science, Management, and Technology**

•***April 5-6, 2012 in Boston, MA***

More details and schedules are available from www.itrcweb.org.

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# Meet the ITRC Instructors

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**Kris Geller** has been working for the State of New Jersey Department of Environmental Protection (NJDEP), Bureau of Environmental Evaluation and Risk Assessment in Trenton since 1989. He is a (Technical Coordinator) providing technical assistance during all phases of site remediation from preliminary assessment through site closure. Kris was part of a team that wrote The Technical Requirements for Site Remediation - NJAC 7:26E. He is the team leader for the ITRC Phytotechnologies team. Prior to his moving to the NJDEP, he spent over 10 years working in the domestic and international petroleum industry. Kris earned a bachelor’s degree in biology from the State University of New York in Oswego, NY in 1974 and a master’s degree in geology from the University of Kentucky in Lexington, KY in 1985.

**Eleanor (Ellie) Wehner** is the Corrective Action Program Specialist for the Remediation Division of the Texas Commission on Environmental Quality (TCEQ) in Austin, Texas. Eleanor has worked with the Remediation Division since 1992. Her work currently involves the management and oversight of the Corrective Action Program for the division. She also functions as program liaison for the Remediation Division to Field Operations, Enforcement and Waste Permits Divisions. Eleanor also serves as the primary State point-of-contact to EPA Region 6 on all RCRA Corrective Action-related issues. Eleanor regularly trains and mentors internal staff and has routinely presented at agency-related conferences. In 2007, she introduced and presented ITRC’s Eco Land Reuse guidance document at TCEQ’s Trade Fair Conference, and at EPA Region 6’s Land Revitalization Conference. Prior to 1992 she worked for 5 years in the environmental consulting field and for the State of PA. Eleanor has contributed to ITRC as a team member for the Ecological Land Reuse, Brownfield, and Phyto Revision teams. She also serves the non profit sector on forest conservation issues as a Field Representative for American Forests. She earned a bachelor's degree in geology from Millersville University of Pennsylvania in 1988, and a master's in geology from Vanderbilt University, in Nashville, Tennessee in 1991. Eleanor is also a certified PG with the TX Board of Professional Geoscientists.

**David Tsao**, PhD, is the deputy manager and HSSE coordinator for the Remediation Engineering & Technology group in BP’s Remediation Management function at their office in Warrenville, IL. He is a three-time chemical engineering graduate of Purdue University (B.S., 1988, M.S., 1990, Ph.D., 1997) where his areas of research included plant biotechnology, pharmaceutical production, plant nutrition, and plant biomass production for space (NASA) applications. Upon graduation, David came to work for Amoco in the Environmental Technology Assessment and Development group where he specialized in the areas of phytotechnologies and the remediation of gasoline oxygenates. Currently, David is responsible for a team of remediation scientists and engineers coordinating, developing, and implementing the technical aspects of all clean up strategies in the Americas. He is also personally active in wetland technologies, landfarming, composting, native prairie restorations, ecosystem developments, biodiversity, and greenhouse gas emissions reduction. Furthermore, David actively participates in the development of these natural clean up technologies, establishes regulatory guidance on their use, and teaches phytotechnologies through the US EPA, Interstate Technology and Regulatory Council, and the Wildlife Habitat Council. David earned a bachelor's degree in 1988, a master's degree in 1990, and a doctorate in 1997, all in chemical engineering from Purdue University in West Lafayette, Indiana.

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## What you will learn…

- Phytotechnologies
  - Are a set of technologies using plants to remediate or contain contaminants
  - Are attractive **Green** alternatives
  - Are applicable to soil, groundwater, surface water, or sediment
  - Are used throughout the world
- This guidance
  - Can be used regardless of what stage your project is in
  - Replaces ITRC Phyto-1, 1999 & Phyto-2 2001
  - Provides a systematic evaluation of the mechanisms and applications available to treat contaminants

Primary goal of this training session:

It is our hope in the weeks and months following this training session to provide you with a sufficient amount of information so that you will feel comfortable using this document as a tool to assist you when faced with evaluating, planning and/or implementing cleanup projects at a site that incorporates phytotechnologies

Phytotechnologies are a set of cleanup technologies that use plants in a controlled manner to remediate or contain contaminants in soil, groundwater, surface water, or sediments.

Plants in general have a unique natural ability to physically draw water, extract toxins and assist in the microbial digestion and/or stabilization of contaminants.

Phytotechnologies also offer an attractive “Green” alternative to conventionally designed (engineered) remediation technologies.

…can potentially be applied to sites either as the sole remedy or as a supplement to conventionally-designed (engineered) remediation systems.

…can also be used to address a wide range of media, contaminants

…phytotechnologies continue to have successful worldwide application & appeal.

… the use and application of Phytotechnologies has been around for years. Therefore, the technology should not be considered innovative, emerging or new. In fact, like any other remediation technology, it continues to be refined while at the same time broadened in its application.

Just some additional background history on this current guidance document….

This document is an update to the Phyto-1 Phytoremediation Decision Tree (1999) and Phyto-2 Phytotechnology Technical and Regulatory Guidance Document (2001).

Concepts from both the 1999 and 2001 documents were merged into this document, effectively replacing the previous documents in entirety.

In addition, this guidance includes new (and most importantly) practical information on the process and protocol for selecting and applying phytotechnologies as remedial alternatives and technical descriptions of phytotechnologies within this document were meant to provide a systematic evaluation of the mechanisms available to treat contaminants. The guidance was also meant to be used regardless of what stage your project is in.

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# Phytotechnologies at Work

•Three year old poplar stand used for hydraulic control and/or remediation of VOCs in groundwater

Surface soil remediation, stabilization and/or sequestration of TPH, PAH, PPM, PCBs and VOCs

No associated notes.

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## Benefits to the Audience

- This guidance provides
  - A practical understanding of Phytotechnologies
  - Concepts, definitions and resources to all users
  - A framework for consultants and regulators to use in the preparation or review of remediation work plans
  - The ability to save time and money
  - Another remediation tool to your personal toolbox

We, as a team, believe the information provided in this new guidance document and conveyed to you in this training session today will provide you with:

a more practical understanding of phytotechnologies

improved familiarity with general phytotechnology concepts, definitions and informational resources available to users of the document

The guidance document was targeted for use specifically by regulators tasked to evaluate and make informed decisions on phytotechnology work plans as well as practitioners in the field who are often tasked with evaluating any number of remedial alternatives at a given site. Several strategically placed “decision trees” within the guidance document also provide a framework that can be used to streamline the decision-making process when tasked to evaluate/apply phytotechnologies. With it being a ‘one stop’ guidance document for evaluating/applying phytotechnologies the document can potentially save you valuable time and money. It also provides a personal benefit in that it simply allows you to add another “technical tool” to your professional toolbox.

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## Key Changes

- FAQ Section
- Revised and upgraded Decision Trees
- Decision Trees incorporated into document
- Organized along a generic project lifecycle

No associated notes.

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# Phytotechnologies

- Use of vegetation to contain, sequester, remove, or degrade organic and inorganic contaminants in soils, sediments, surface water, and groundwater

**Cabin Creek WV: before (above) and 8 years later (below)**

Need for Terminology clarification:

When we we're first tasked to revise the document, one of the first issues we noticed was an apparently large amount of variability with just the basic terminology that is currently used within the field of phytotechnologies. We as a team made a notable distinction between the basic terms 'Phytoremediation' and 'Phytotechnologies'….

Phytoremediation is defined simply as the use of plants to remediate contaminated soil, sediments, surface water, or groundwater.

Phytotechnologies is a set of technologies using plants to remediate or contain contaminants in soil, sediments, surface water, or groundwater…both applications are common in that they both use plants.

Phytotechnologies include containment strategies in addition to phytoremediation strategies.

From a regulatory perspective, clean up goals can be remediation, containment, or both.

In summary, just remember that Phytoremediation is really just one subset of phytotechnologies….and Phytotechnologies is really the bigger, broader term…

Photos full scale Rhizodegradation remediation project 10 Hectare site

Before: Cabin Creek, West Virginia, 1999 – Former Oil Refinery and Tank Farm contaminated with >5000 mg/kg TPH…

After: in eight years, poplar trees were well established and soil concentrations have decreased by 75%

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## Advantages

- Broad application relative to treatment systems
  - Example in Section 1.4
- Sustainable green technology
- Solar-powered improves air quality and sequesters greenhouse gases
- Minimal air emissions, water discharge, and secondary waste
- Controls erosion, runoff, infiltration, and fugitive dust emissions
- Passive and in-situ
- Favorable public perception
- Educational opportunity

This slide is basically presenting a list of Advantages…I would really like to focus on just a few on this slide that I feel provide an important benefit/advantage when applying Phytotechnologies to a remediation project…

First one, "Sustainability", is one of those hot topics right now, just in the past few years a lot of states and federal agencies are starting to talk about sustainable solutions to remediation. Because phytotechnologies are a solar powered system in itself…the plants are simply powered by the sun to do the remediation. In general, unless you have monitoring equipment associated with the project that requires electricity, you don't need any supplemental energy other than solar power to run the entire system. So in a way it's a very green, sustainable technology in its own right.

Next bullet, you are also potentially helping to reduce primary green house gases and also potentially reducing other types of emissions, waste generation, water discharge and so on…so in a way you could use phytotechnologies as a means to create a more sustainable remediation approach.

The plantings themselves can be used to control soil and sediment erosion, surface water runoff/infiltration as well as suppress dust emissions at a site. In general, improve the overall environmental stability of a site.

In addition, being inherently green in nature, phytotechnologies can offer favorable public perception by improving the overall aesthetic-look of a site. Could result in a marketing advantage, improved reputation for a company in the surrounding community.

There also may be an offer of an Educational opportunity to the community…it can be used to teach people about ecology, environment, plants…it simply is a good way/method to provide an opportunity for a lot of hands on education for kids. This technology is unique in that it does provide that benefit.

In comparison to alternative cleanup technologies, phytotechnologies are one of the few that can be applied to both organic and inorganic contaminants and to soil/sediment, surface water, and groundwater. MOST importantly, it can do it SIMULTANEOUSLY. In most other remedial approaches, these combinations would have to be addressed using a treatment train…

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## Advantages (continued)

- Improves aesthetics including reduced noise
- Applicable to remote locations, potentially without utility access (critical utility is a supplemental source of irrigation)
- Can be used to supplement other remediation approaches or as a polishing step
- Can be used to identify and map contamination
- Can be installed as a preventative measure, possibly as a leak detection system
- Lower maintenance, resilient, and self-repairing
- Creates habitat (can be a disadvantage – attractive nuisance)
- Provides restoration and land reclamation during clean up and upon completion
- Can be cost competitive

Others advantages in particular to mention on this slide…

Phytotechnologies can be used to identify and map contamination. The USGS recently published a document on how to use trunk coring samples to help map contamination plumes. For example if you know you have a release at a site but haven't delineated the extent of the plume…one of the things you could do (assuming that you already know that the groundwater is fairly shallow and within the root zone) is map the plume by using trunk cores from trees growing at the site. This can be used as a prelude to installing permanent wells at your site…instead of installing a series of temporary piezometers to identify the extent of the plume. You are simply using your trees to initially map that plume. In the time it takes to install 1 peizometer, you could do several dozen trunk cores and get a much larger data set from the trunk cores than you would from that single peizometer. This way you would be saving a lot of time and effort in creating that initial view of where your contaminant extent might be. **Important point** is that it is not meant to replace the need to install monitor wells but you can use these tree cores to initially map the extent of contamination at a site as a the first step to determine where you want to place your permanent monitor wells.

Phytotechnologies can also be used as a form of preventative measure…Certain tolerant species of plants with an ability to remediate gasoline could be incorporated into the design of landscapes at retail gas stations as a preventative measure. Ex..new retail site strategically-landscaped with these plant species…in the event of an accidental spill of gasoline from a pump station onto the ground, the topography could direct at least some of the spill toward these specially vegetated areas. The plants were put in there to specifically be able to deal with and remediate the contamination. Ultimately, may potentially reduce overall environmental liability for the site.

Phytotechnologies may also have some potential applications in the area of leak detection….just as there are certain plants that show an extreme tolerance for being able to handle high concentrations of contaminants, there are also (on the flip side) plants that are highly reactive. For example, certain species of plants will immediately wilt in the presence of just gasoline vapors. So it is possible to consider using some of the more highly susceptible species of plants for just leak detection applications.

These technologies can also be very low maintenance and are oftentimes self repairing

In addition, with the application of phytotechnologies at a site you always need to remember that you also may be inadvertently (or unintentionally) adding an ecological enhancement to a site…creating new wildlife habitats, and also fate and transport pathways that may never have existed at the site prior to applying a particular phytotechnology. This can be both an advantage and a disadvantage…

Lastly, phytotechnologies can be cost competitive when compared to traditionally designed (engineered) remediation systems. In some ways phytotechnologies could also provide a marketing advantage (marketing the use of a 'Green' technology has the potential to attract more customers). In addition, there may be an offer of a tax advantage through a conservation easements, and there may be a potential to offset a pending NRDA claim (for projects that include a sustainable ecosystem).

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# Limitations

- Depth
  - Root influence
- Area
  - Require larger tracts of land than other technologies
- Time
  - Timeliness
  - Susceptible to seasonal and diurnal variations

Phytoremediation Limitations

The technology is fabulous, it has a lot of applications, and a lot of potential ways to use it. You can use it for so many different types of contaminants/media, even air. There is a broad applicability, but as with every technology, there is always the potential for limitations. Some of the ones that are show stoppers would be:

Depth…limited by the rooting penetration…it's really the limitation of the impact that plant roots have on the subsurface soil. Local soil conditions (nutrient content, moisture, compaction, etc.) will dictate the ultimate depth to which any plant will reach. General rule of thumb is that 70-80% of the root structure of a plant will be within the top 1-2 feet of surface (including tap rooted species) with exploratory roots sent deeper as well as laterally. Typical rooting depths for grasses and forbs are on the order of 1-2 feet; however, some prairie grasses have root systems that can reach 10-15 feet. Typical rooting depths for trees are on the order of 10-15 feet (maximum down to 25 feet bgs). Another rule of thumb, is that trees will not access deeper than 5 feet into the saturated zone.

If you don't have enough land to plant enough plants…the area is not large enough you really will need to start looking for another technology or supplementing your plants with another technology. Or (on the flip side) you may need to look at supplementing your technology with plants.

Third, 'Time"..Phytoremediation is a long term remedial approach, not a quick fix. So it is not on the same time scale as a dig/dump type remedial approach. The limitations shown …concentration of contaminants might simply be too toxic to the plant..

Others:

Phytotoxicity: You may have a site that is simply too toxic to support plant growth. One quick way to tell when initially evaluating a site….the first thing you may want to do is look to see if it has any pre-existing plants growing on it. If you have a moonscape type situation (ex. fly ash sites, mine tailings) with absolutely no plant growing on it is most likely going to end up being a potentially phytotoxic environment.

Fate and transport….Specifically when applying phytovolatilization to a site there may be a potential to volatilize certain contaminants into the atmosphere. You may need to ask that questions, Is that going to be an acceptable risk at my site? Certainly there are certain acceptable risk levels that have to be discussed, in some cases it may limit applicability or in other cases it won't.

Are you potentially introducing new potential receptors to contaminants in the plant…again, these are things that need to be discussed in detail to determine if it is an acceptable risk at a site.

Climate conditions (including altitude). Is the climate/elevation going to be able to support the plants that you want to use? Other things such as site soil condition, nutrient content are also important. Are you going to have to do a lot of soil conditioning with nutrients or tilling is that going to be cost effective? These things may possibly limit the application of phyto to your site.

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## Regulatory Issues Associated with Phytotechnologies

- Most common concerns
  - Timeliness
  - Contaminated plant disposal
  - Ecological concerns
  - Are the contaminant levels too high for this technology
  - Media transfer
  - Toxicity of by-products (e.g. Biodegradation)
  - Health and safety
    - Implementation
    - Operation
    - Closure

This slide was put in to summarize some of the most frequently encountered regulatory concerns we as a team have encountered during past ITRC internet training sessions on the previous two phyto guidance documents. As mentioned earlier…sometimes the best response that can be provided to some of the most common questions we've encountered as a team about phytotechnologies is the statement, "It depends…"?! Many site specific factors influence the application of phytotechnologies. As with evaluating any remediation technology at a site, some of the issues that will need to be looked at a little closer when applying phytotechnologies to a site:

Timeliness: In some cases, the application of phytotechnologies can have an immediate effect on contaminant concentrations upon planting. In other cases, it may require several seasons before the plant can interact with a contaminated zone at depth. Another influencing factor may be whether the plant itself is directly or indirectly involved with remediating the contaminant (e.g.…phytodegradation versus the plant simply stimulating the biodegration process.)

Contaminated plant disposal: Specific analysis of plant and core tissues sampling will determine if the plant is safe. It is a little different than sampling contaminated media (e.g. soil/gw). Section 2.5.3.3. (Fate and Transport in the Plant) provides some additional discussion of this topic.

Ecological concerns: As mentioned earlier, with the application of phytotechnologies at a site you always need to remember that you also may be inadvertently (or unintentionally) adding an ecological enhancement to a site…creating new wildlife habitats, and also fate and transport pathways that may never have existed at the site prior to applying a particular phytotechnology.

Are the contaminant levels too high for this technology: If you have a site is contaminated first thing you may want to do is look to see if you have plants growing on it. If you have a 'moonscape' type situation (ex. certain fly ash, mine tailings sites) with absolutely no plants growing on it is most likely going to end up being a potentially phytotoxic environment. At this point it may be a good idea to look at other alternative technologies better suited to address the contamination/hot spots such as dig and haul (at least initially). Phytotechnologies could still potentially be used at the site (but perhaps later on down the road) in the remediation process.

Media transfer & Toxicity of by-products: Again, the only way to know this is to actually conduct specific analysis of plant and core tissues sampling to determine if the plant is acting to transfer any contaminants from one media to another (e.g. groundwater to air via phytovolatilization). Also to determine if the plant itself is creating any byproducts as a result of physically taking that contaminant in.

Health and safety (Implementation, Operation, Closure): Environmental regulations governing cleanup at all sites are specifically geared to protect 'human health and the environment.' Therefore, developing and managing phytotechnology systems are similar to any in-situ remediation system. As with any cleanup technology, there are six general phases that exist in developing and managing an optimal remediation system (…Assessment, Remedy selection, Design and implementation, O&M, Monitoring, and Closure).

Need to stress that none of the issues presented in the slide are actual regulatory barriers to applying phytotechnologies to a particular site. Just like any remediation technology….These are simply things that may need to be looked at a little closely when initially looking at applying phyto to a site.

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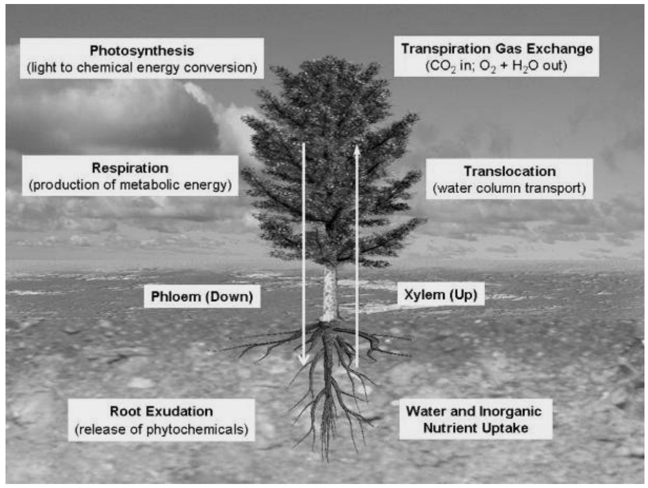
## Plant Physiology

- Inorganic nutrition
- Photosynthetic production of plant material
- Evapotranspiration




Basic Plant Physiological Processes: Basically, there are 2 different vascular pathways. One (on left side of the slide) that takes the energy and the chemicals created during photosynthesis and respiration and distributed it from the top down (if you will) throughout the plant and even in some cases exuding some of those chemicals that are produced during photosynthesis out through the root system.

On the other side (right side of the slide) you have the water and inorganic nutrient uptake occurring from the roots upward…this is driven by the process of transpiration occurring in the leaves but the entire water column is moving throughout the plant through translocation.

The vascular tissues themselves are the PHLOEM (on left side of the slide: movement down to roots) and XYLEM (roots upward).

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# Plant Tissue Concentrations and Essential Nutrients (Table 1-1)

| | Nutrient Element | Symbol | Tissue Concentration (ppm) | Available Forms |
|---|---|---|---|---|
| Organic Biomass | Carbon | C | 450,000 | $CO_2$ |
| | Oxygen | O | 450,000 | $CO_2$, $H_2O$ |
| | Hydrogen | H | 60,000 | $H_2O$ |
| Inorganic Macronutrients | Nitrogen | N | 15,000 | $NO_3^{2-}$, $NH_4^+$ |
| | Potassium | K | 10,000 | $K^+$ |
| | Calcium | Ca | 5,000 | $Ca^{2+}$ |
| | Phosphorus | P | 2,000 | $HPO_4^{2-}$, $H_2PO_4^-$ |
| | Magnesium | Mg | 2,000 | $Mg^{2+}$ |
| | Sulfur | S | 1,000 | $SO_4^{2-}$ |
| Inorganic Micronutrients | Iron | Fe | 100 | $Fe^{2+}$, Fe-chelate |
| | Chlorine | Cl | 100 | $Cl^-$ |
| | Manganese | Mn | 50 | $Mn^{2+}$ |
| | Zinc | Zn | 20 | $Zn^{2+}$ |
| | Boron | B | 20 | $BO_3^{3+}$ |
| | Copper | Cu | 6 | $Cu^{2+}$ |
| | Molybdenum | Mo | 0.1 | $MoO_3^-$ |

This slide lists C, O, H and the thirteen essential inorganic plant nutrients (N, P, K, Ca, Mg, S, Fe, Cl, Zn, Mn, Cu, B, and Mo) that can potentially be taken up by the root system as dissolved constituents in soil moisture that are required by the plant for growth, development or reproduction. These nutrients are acquired by the plant either passively via evapotranspiration or actively through transport proteins that are associated with the root membrane of the plant (once inside the root system, the dissolved nutrients can be transported throughout the remainder of the plant via upward flow in the xylem). In addition to these essential nutrients, other non-essential inorganics such as various common contaminants (i.e. salts, Pb, Cd, As) can also potentially be taken up by the plant. Specific mechanisms to be discussed a few slides later…

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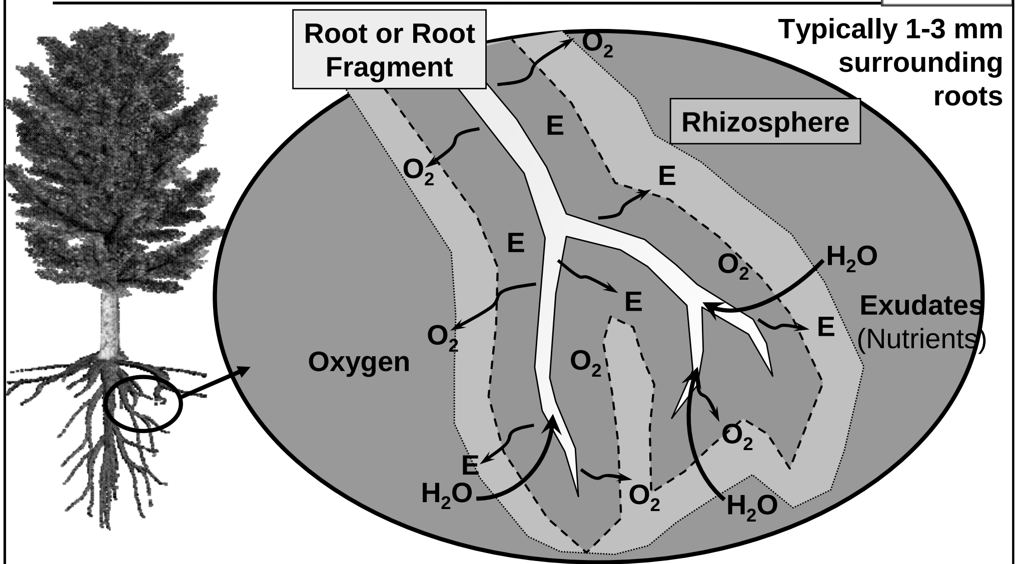
# Plant Physiology: Root-Zone Rhizosphere (Figure 1-2)




Nutrients are transported via the phloem down to the roots where they are exuded as a carbon source. Bacteria and fungi tend to thrive in the immediate vicinity of the roots. This region of soil, roots and organisms is defined as the rhizosphere and extends out approximately 1-3 mm from the root surface. Highly vegetated soils will have about 3-4 order of magnitude higher soil organism ‘population’ in comparison to a non-vegetated soils.

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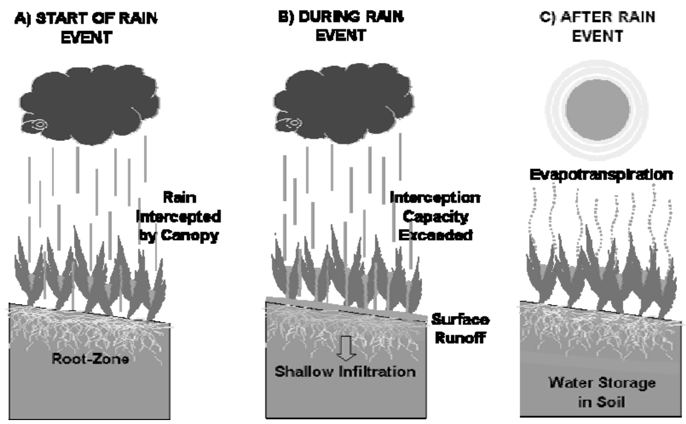
# Plant Physiology-Evapotranspiration

(Figure 1-3)

- Rain interception capacity
- Transpirational uptake




Evapotranspiration offers another unique physiological process unique to plants. This is Figure 1-3 in the Phyto-3 tech reg guidance document and is showing the 'Rain Interception Capacity'. Step A (rain begins to fall; some water retained on plant)..Step B (plant interception capacity exceeded)… Step C (water evaporates off the plant surface; also transpiration occurring)

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# Phytotechnology Mechanisms

**"**Summary" (Table 1-3)

| Mechanism | Description | Clean Up Goal |
|---|---|---|
| 1. Phytosequestration | The ability of plants to sequester certain contaminants into the rhizosphere through exudation of phytochemicals, and on the root through transport proteins and cellular processes | Containment |
| 2. Rhizodegradation | Exuded phytochemicals can enhance microbial biodegradation of contaminants in the rhizosphere | Remediation by destruction |
| 3. Phytohydraulics | The ability of plants to capture and evaporate water off of the plant, and take up and transpire water through the plant | Containment by controlling hydrology |
| 4. Phytoextraction | The ability of plants to take up contaminants into the plant with the transpiration stream | Remediation by removal of plants |
| 5. Phytodegradation | The ability of plants to take up and break down contaminants in the transpiration stream through internal enzymatic activity and photosyntheticoxidation/reduction | Remediation by destruction |
| 6. Phytovolatilization | The ability of plants to take up, translocate, and subsequently transpire volatile contaminants in the transpiration stream | Remediation by removal through plants |

Table 1-3 provides a summary of 6 phytotechnology mechanisms. This table is used to show you what cleanup goals would equate to a particular phytotechnology mechanism. Note that just one phytotechnology mechanism would potentially harness several different mechanisms, particularly if your cleanup goal involves both the containment and remediation of a site.

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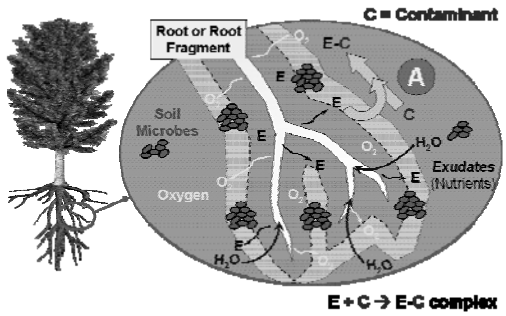
## Phytosequestration Mechanisms

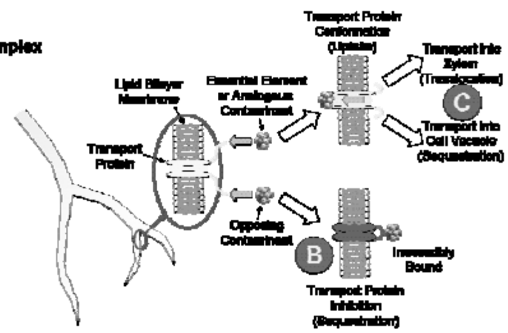
(Figure 1-5)




A. Phytochemical Complexation

B. Transport Protein Inhibition

C. Vacuolar Storage



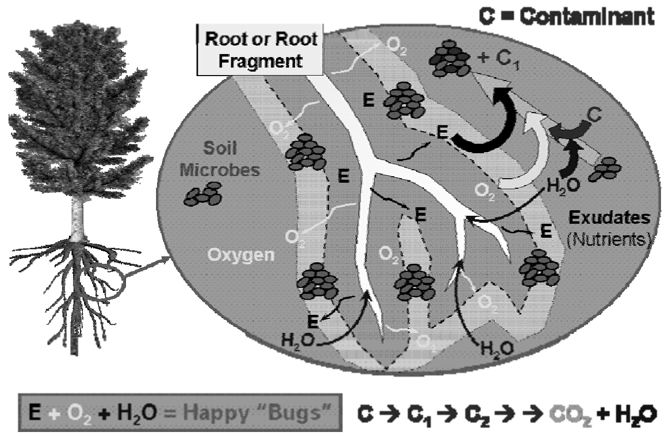

[First mechanism on table 1-3] Phytosequestration. Phytochemical Complexation…nutrients/exudates are interacting with the contaminants (id as the red c in the slide, upper right hand of the brown oval) and actually be complexing with that contaminant. Two sub mechanisms within phytosequestration are identified on the bottom left hand of the slide (Transport Protein Inhibition and Vacuolar Storage). In the Transport Protein Inhibition submechanism…Plant roots are made up of what are called lipid bilayers. These are membranes that the root is comprised of. And within that membrane are transport proteins. Typically these transport proteins take up essential nutrients and different inorganic elements that plants require for growth and metabolism or reproduction. In many cases they require these transport proteins to actually get into the plant. Root membrane is acting as a protection barrier…it is acting to selectively take up the essential elements that it needs while restricting the uptake of those elements. So this irreversible binding prevents that non essential element from entering into the plant and basically turns off that entire protein so it is no longer an operating protein anymore. This process is shown in the lower right diagram (Yellow B in the Green circle).

The other submechanism is called Vacuolar Storage. In this process shown in the lower right diagram (Yellow C in the Green circle). If the nonessential element is able to “trick” that protein and allow it enter and compartmentalize them. The vacuole can be used as a storage receptacle for storage of excess elements. So if there is an excess of amount of nitrogen/potassium or some other inorganic element that it actually does need, but doesn’t need that amount right away. It will store it in the vacuole of the cell and then slowly use it up as it needs to.. The other function of the vacuole is to function as the waste receptacle of the cell.

# Rhizodegradation-Rhizosphere

**“1st Contact between Plant and Contaminant”**

(Figure 1-6)




Rhizodegradation…The first area of contact between soil or gw contaminant and a plant is in the zone called the ‘rhizosphere’ of the soil. This is basically is the immediately soil surrounding the root…Rhizosphere itself is a highly bioactive zone (typically supported by the plant itself) through nutrient exudation (..again photosynthetic chemicals produced in the plant that end up being exuded into the surrounding soil).

Chemical processes (at bottom of slide) are described in Section 1.2.2. What you are looking at in the slide is a contaminant that is being interacted upon by a microbe (green ovals in the slide) they are taking that and using it as a source of carbon or source of energy. Again in an oxygenated and water hydrated environment the microbes will either create a biomass for themselves which is represented by the cluster of green and red ovals in the slide where it is creating more cell mass or it is using it for energy for itself. The original contaminant/parent compound (c) creates byproducts (c1)…process continues with production of additional byproducts (c2), and eventually exhausts itself down to CO2 and water. Basically what you are looking at is bioremediation that is just stimulated by the plant.

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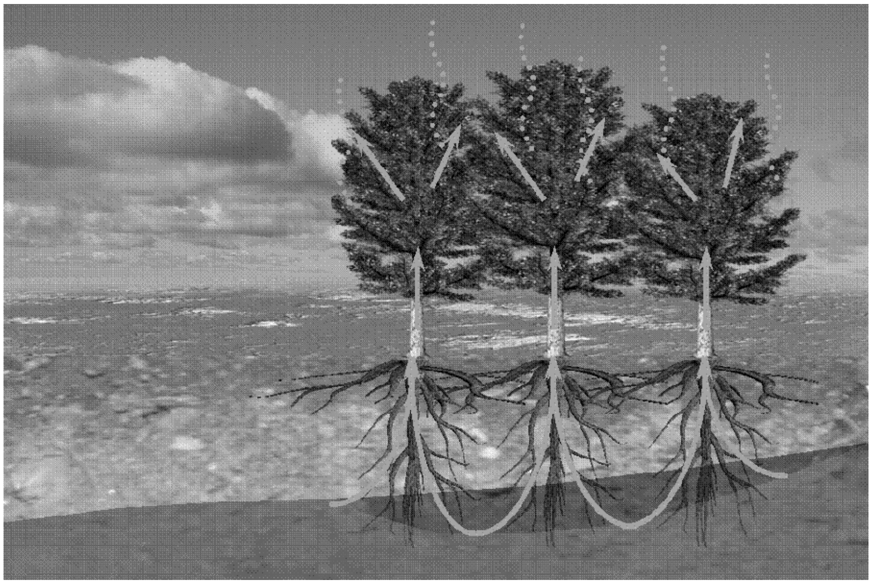
# Phytohydraulics

(Figure 1-7)



Phytohydraulics.  Slide is illustrating the process of transpiration.  In many applications what you want to do is actually access groundwater directly.  Assume movement of groundwater flows right to left on the slide so you would plant trees to intercept that groundwater.  Cone of depression forms. Will fluctuate daily…because your plant will turn on and off (a cyclical pump if you will) turning on a off each day as the sun comes up and goes down.

Role of ‘phreatophytes’…species ‘***Salicaceae***’: include cottonwoods, poplars, willows in phytohydraulics.

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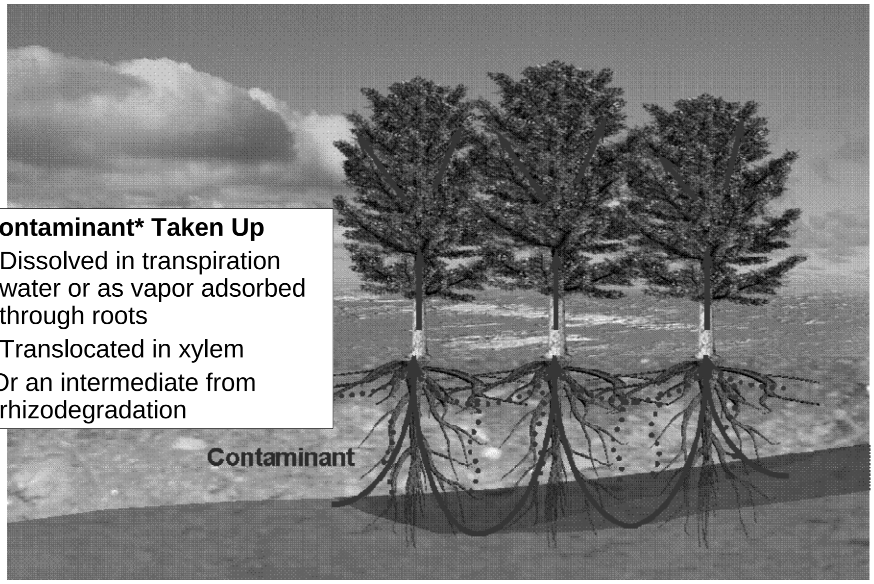
# Phytoextraction Mechanism

(Figure 1-8)




**Contaminant* Taken Up**

- Dissolved in transpiration water or as vapor adsorbed through roots
- Translocated in xylem

*Or an intermediate from rhizodegradation

Phytoextraction. Removal of the contaminant using the plant as the mechanism to make it more accessible. So phytoextraction…is looking at the simple uptake of a contaminant into a plant.

Most common contaminants that can be phytoextracted…inorganics; however, organic contaminants can also be subjected to this mechanism. The primary difference between an organic/inorganic contaminant…. An organic chemical can be degraded or broken down further by what is going on in the plant. Rule of thumb: readily bioavailable inorganics for plant uptake will include As, Cd, Cu, Ni, Se, and Zn.  Cr, Pb and Uranium are not very bioavailable.

Role of log KoW (octanol water partition coefficient) with respect to organics.  Log KoW values that range between 1 and 3.5 (benzene, toluene, TCE) are able to be easily absorbed by the plant.

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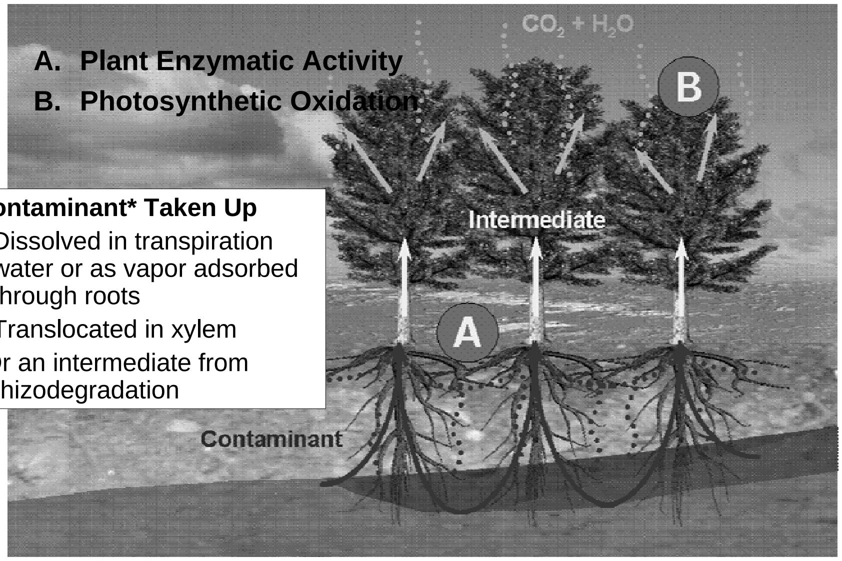
# Phytodegradation Mechanisms

(Figure 1-9)




**Contaminant* Taken Up**
- Dissolved in transpiration water or as vapor adsorbed through roots
- Translocated in xylem

*Or an intermediate from rhizodegradation

Phytodegradation…Role of plant enzymes in pytodegradation. In addition to these plant enzymatic activities/photosynthesis will be creating a highly oxidative-reductive cycle within the plant…phytosynthetic oxidation. "A" showing you where the 'plant enzymatic activity' would most likely be occurring. "B" showing you where 'Photosynthetic Oxidation' would most likely be occurring.

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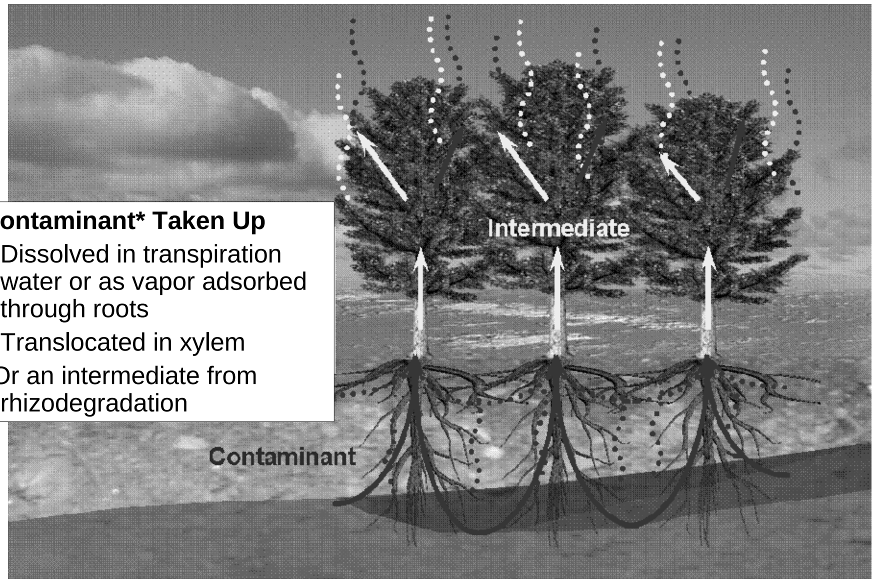
# Phytovolatilization Mechanism

(Figure 1-10)




**Contaminant* Taken Up**

– Dissolved in transpiration water or as vapor adsorbed through roots
– Translocated in xylem

*Or an intermediate from rhizodegradation

Phytovolatilization…volatilization via the leaf stomata and plant stems. There are some instances where some organics and even some inorganic chemicals will volatilize out of a plant (this is known as phytovolatilization). In many cases, for organics it could be simple mass loading where the uptake of a contaminant or byproduct is faster than the rate it can be broken down in the plant. Contaminants are dissolved in the transpiration water or as vapor adsorbed through roots/translocated in xylem.

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# Phytotechnology Applications and Treatment Goals (Table 1-5A)

| Media | Application | Potential Mechanisms | Comments |
|---|---|---|---|
| Soil<br>Sediment<br>(impacted) | **Phytostabilization Cover** (soil/sediment stabilization) | Phytosequestration<br>Phytoextraction (no harvesting)<br>Adsorption (abiotic)<br>Precipitation (abiotic)<br>Settling/Sedimentation (abiotic) | Also controls soil erosion by wind/water<br>See ITRC WTLND-1, 2003 for sediment aspects |
| Surface Water (clean) | **Phytostabilizaion Cover** (infiltration control) | Phytohydraulics (evapotranspiration)<br>Run-off (abiotic) | Vertical infiltration control<br>See ITRC ALT-1, 2003; ALT-2, 2003; ALT-3, 2006; ALT-4, 2006 For ET covers |
| Surface Water (impacted) | Pond/Lagoon/Basin<br>**Riparian Buffer** | Phytosequestration<br>Phytohydraulics (evapotranspiration)<br>Phytoextraction (no harvesting)<br>Evaporation (abiotic)<br>Infiltration (abiotic) | See ITRC WTLND-1, 2003<br>Includes wastewater<br>Also controls soil erosion by water run-off |
| Groundwater (clean) | **Tree Hydraulic Barrier**<br>**Riparian Buffer** | Phytohydraulics (evapotranspiration) | Lateral migration control |
| Groundwater (impacted) | **Tree Hydraulic Barrier**<br>**Riparian Buffer** | Phytosequestration<br>Phytohydraulics (evapotranspiration)<br>Pytoextraction (no harvesting) | Lateral migration control |

The tables (Table 1-5A) and the next (Table 1-5B) were taken from the ITRC guidance document. They are meant to highlight 'containment applications'…so if your strategy is to do containment at your site and your media (in that column on the left)…is soil, sediment or surface water or groundwater this table provides some applications you might want to consider. Not just the application is presented, but what mechanisms are relevant for that application. It gives you a quick pick list of specific phytotechnology applications depending on the type of media (clean or impacted) and depending on your specific treatment goal (either containment or remediation or both). Other applications for the containment side…are riparian buffers, ponds, lagoons, basins… were included because you could have submerged vegetation in your pond or lagoon that could also be contributing to some of the stabilization or remediation.

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# Application and Mechanisms for Treatment Goals (Table 1-5B)

| Media | Application | Potential Mechanisms | Comments |
| --- | --- | --- | --- |
| **Soil Sediment (impacted)** | **Phytoremediation Groundcover** | Rhizodegradation<br>Phytoextraction (with harvesting)<br>Phytodegradation<br>Phytovolatilization<br>Biodegradation (microbial)<br>Oxidation/Reduction (abiotic)<br>Volatilization (abiotic) | Phytohydraulics (evapotranspiration) assumed for phytoextraction, phytodegradation, and phytovolatilization |
| **Surface Water (impacted)** | Pond Lagoon Basin<br>**Riparian Buffer**<br>Constructed Treatment Wetland | Rhizodegradation<br>Phytoextraction (with harvesting)<br>Phytodegradation<br>Phytovolatilization<br>Biodegradation (microbial)<br>Oxidation/Reduction (abiotic)<br>Volatilization (abiotic) | See ITRC WTLND-1, 2003<br>Includes wastewater and extracted groundwater<br>Phytohydraulics (evapotranspiration) assumed for phytoextraction, phytodegradation, and phytovolatilization |
| **Ground water (impacted)** | **Phytoremediation Tree Stand**<br>**Riparian Buffer** | Rhizodegradation<br>Phytoextraction (with harvesting)<br>Phytodegradation<br>Phytovolatilization<br>Oxidation/Reduction (abiotic)<br>Biodegradation (microbial) | Phytohydraulics (evapotranspiration) assumed for phytoextraction, phytodegradation, and phytovolatilization |

Table 1-5B is used when looking at ‘Remediation’ as your treatment goal. Again these two tables are meant to give you a quick pick media. What kind of applications are relevant to it? What mechanisms do you have at your disposal? And then some comments about that particular situation. Not all of the mechanisms will be applicable to your site. Based on different plant species, or in some cases some of the chemicals will simply not be able to be degraded within the plant or in different zones of the plant’s system.

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# Applications
# Summary of Case Studies (Table 1- 6)

- Phytostabilization cover
  - Stabilization
    - Typical focus of effectiveness is 1-2 feet
  - Infiltration control
- Phytoremediation groundcovers
- Tree hydraulic barriers
- Phytoremediation tree stands
  - Species such as prairie grasses have root systems that can reach 10 to 15 ft below surface given optimal soil and moisture conditions
- Riparian buffers

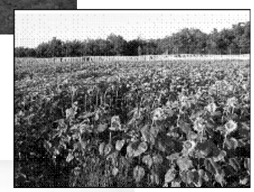

Table 1-6 presents a summary of case studies that are highlighted in the guidance document.

Phytostabilization covers

Phytoremediation groundcovers

Tree hydraulic barriers

Phytoremediation tree stands

Riparian buffers

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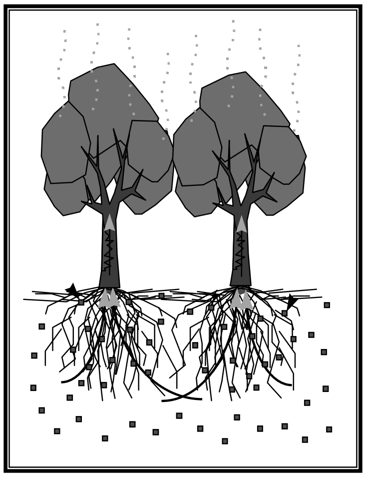
## Questions & Answers



Questions

and

Answers

No associated notes.

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# Project Management for Phytotechnologies

•**Document is organized along a <u>generic project lifecycle</u>**

Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

| Phytotechnology not selected as the remedy yet | Phytotechnology selected as a remedy |
|---|---|
| Site Assessment → Remedy Selection | Design & Implementation → Operation, Maintenance, Monitoring → Closure |

- Front-end stages
  - Specific information needed to evaluate the technical feasibility of phytotechnologies
  - Other decision factors for selecting phytotechnologies
- Tail-end stages
  - Detailed how to… information
  - Plus, how these stages impact the front-end stages, particularly cost factors for Remedy Selection

No associated notes.

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# Site Assessment

Section 2.2

Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

**General Information**

- Information collected for any site
  - Site description/history
  - Contaminant assessment
    - Soil/sediment, groundwater, surface water data
  - Hydrogeological conditions
  - Exposure/risk pathways
- What of this information would be used to evaluate phytotechnologies?

**Phyto-Specific Information**

- Additional information to collect (or begin to as standard practice)
  - Soil health/agronomics
  - Climate conditions
  - Existing vegetation

No associated notes.

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# Using General Assessment Information

## 2.2.1 Defining Project Objectives

Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

**Output of Site Assessment**

- Impacted media
  - Soil/sediment
  - Surface water, groundwater
- Contaminant
  - Organic, inorganic
  - Concentrations, composition
- Exposure/risks
  - Human/ecological receptors, pathways
  - Land use

**Input into Project Objectives**

- Containment
  - Phytostabilization Cover
  - Hydraulic Tree Barrier
- Remediation
  - Phytoremediation Groundcover
  - Phytoremediation Tree Stand
- Containment and remediation
  - Riparian Buffer
  - *Combined Cover*
  - *Combined Tree Stand*

More detailed list of containment/remediation phytotechnologies provided earlier

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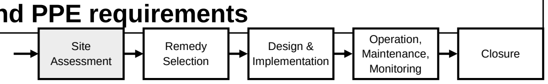
# General Assessment Information Relevant for Phytotechnologies

•Site Description/History (Example Content in Table 2-3)

| | |
|---|---|
| **Soil Sciences/Agronomy** | • Surface features and obstructions **to design the implementation and select planting equipment**<br>• Historic use of pesticides at the site or on adjacent sites (spray drift) **to evaluate plant establishment issues** |
| **Hydrology/Geology** | • Surface topography **for determining runoff characteristics for irrigation** |
| **Plant Biology/Botany** | • Location of water bodies, standing water, or inundation **for plant selection** |
| **Environmental Engineering** | • Surface features, grade, and obstructions **to determine area available for planting and constructability**<br>• Infrastructure and utilities **that can support the phytotechnology system** |
| **Field and HSE Management** | • Utilities and surface grade **to evaluate implementability (health and safety), utility clearance, slips/trips/fall potential, and PPE requirements** |




No associated notes.

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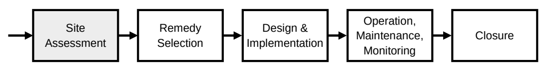
# General Assessment Information Relevant for Phytotechnologies

- **Skills:** **(Table 2-1)**
  - **soil sciences/agronomy**
  - **plant biology/botany**
  - **risk assessment/toxicology**
  - **environmental engineering**
  - **economic analysis**
  - **hydrology/geology**
  - **environmental sciences**
  - **regulatory interpretation**
  - **field & HSE management**
- **Contaminant Assessment**
  - Concentration, composition, vertical/horizontal extent, media, etc.
  - **Fate and transport, plant screening and testing, waste handling, PPE**
- **Hydrogeological Conditions**
  - Water table depths, flow, conductivity, gradient, soil type, vertical profile, geochemistry, GW-SW interface, etc.
  - **Plant selection, rooting depths, hydraulic capture design and modeling**
- **Exposure Assessment**
  - Water bodies, wetlands, ecological, local community
  - Future site use (discussed later)
  - **Stormwater/runoff management, attractive nuisances, security**




No associated notes.

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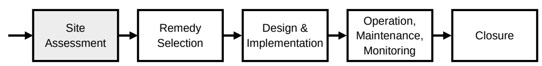
# Phyto-Specific Assessment Information (Content of Table 2-4)

- **Skills:** (Table 2-1)
  - **soil sciences/agronomy**
  - **plant biology/botany**
  - **risk assessment/toxicology**
  - **environmental engineering**
  - **economic analysis**
  - **hydrology/geology**
  - **environmental sciences**
  - **regulatory interpretation**
  - **field & HSE management**
- **Soil/Agronomic Conditions**
  - Soil structure, compaction, fertility, nutrient content, etc.
  - **Plant nutrition, fertilization/irrigation needs, plant selection/screening, implementability**
- **Climatic Conditions**
  - T, RH, P, growing season, frost dates, XX-yr flood, drought, storm events, etc.
  - **Water management, plant selection/screening, scheduling, contingencies**
- **Existing Vegetation**
  - Scientific/common names, type/form of vegetation, ecological characteristics
  - **Plant selection, herbicide management, noxious/invasive control, T/E species**




No associated notes.

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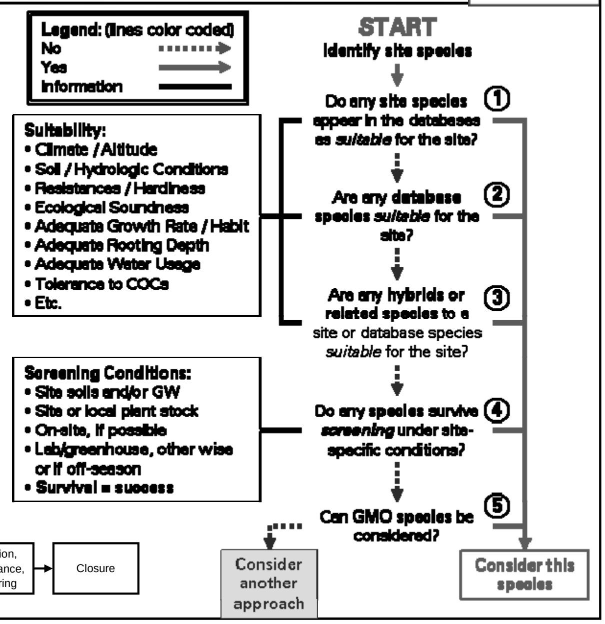
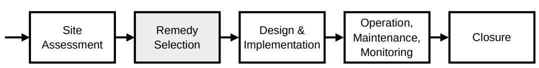
# Plant Screening Process

Figure 2-1

**2.3 Remedy Selection**

- Uses survey of existing species at the site as the basis
- Answers the basic question: Are there candidate species that can be used?
  - **If yes**, **consider phyto**
  - **If no**, **consider other remedial approaches**




Species found in phytotechnology databases AND currently growing at the site

Species found in phytotechnology databases AND suitable to the region but not currently growing on the site

Hybrid or species related to a species identified as a candidate in either #1 or #2

Species NOT found in the databases (or test conditions that are too dissimilar) but currently growing at the site or in the region

Genetically modified organism (GMO) species designed specifically to conduct the desired phytotechnology

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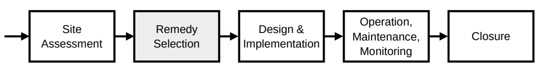
# Plant Databases

- Environment Canada (Terry McIntyre): PhytoREM
  - MS Access Database
  - Al, As, Be, Cd, Cs, Co, Cu, Cr, Pb, Mn, Hg, Mo, Ni, Pd, Pt, Ra, Sr, U, Zn
  - 775 species: tolerant, precipitator, hyper/accumulator
- U. Saskatchewan (J. Germida): Crude Oil Database
  - Species by ecotype
- BP (D. Tsao): Gasoline Database
  - Tolerance of landscape species and others
- ITRC Appendix B (D. Tsao): Literature Database (up to 1999)
  - Metals, rads, nutrients, petroleum, CVOCs, pesticides
  - Water usage, rain interception




No associated notes.

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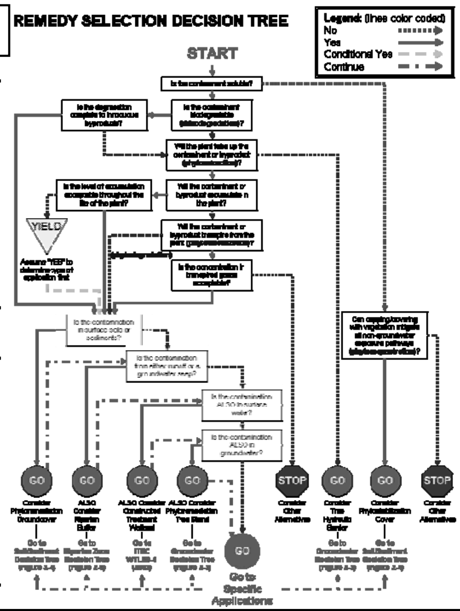
# Remedy Selection Decision Tree

Figure 2-2

Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

- ▶ Questions to determine applicable mechanisms
  - Determines: containment, remediation, or both
  - See Tables 1-5A&B (slides 27 & 28)
- ▶ Questions to determine possible applications
  - Groundcover, trees, and riparian systems (GO)
  - Recommend other alternatives possible (STOP)




No associated notes.

# Groundwater Decision Tree

Figure 2-3

Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

- ▶ Questions based on Site Assessment information to determine applicability to Groundwater
- ▶ Decision Tree for Tree Systems
  - Tree Hydraulic Barriers
  - Phytoremediation Tree Stands

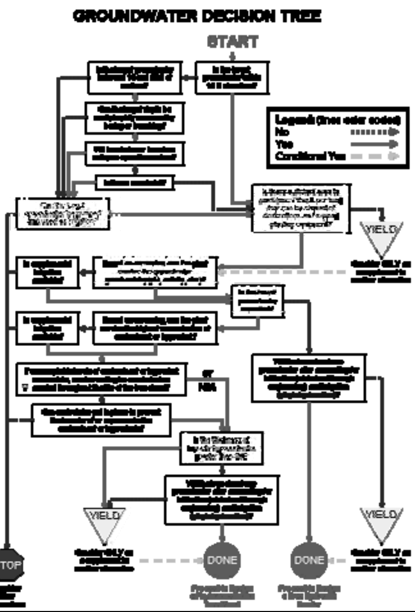
DONE

- ▶ Recommend other alternatives

STOP

- ▶ Recommend only as a supplement to another alternative

YIELD



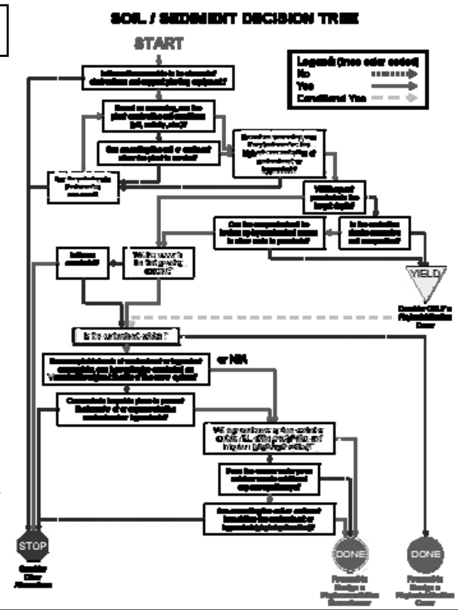

No associated notes.

41

# Soil/Sediment Decision Tree

Figure 2-4

Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure




- Questions based on Site Assessment information to determine applicability to Soil/Sediment
- Decision Tree for Groundcovers
  - Phytostabilization
  - Phytoremediation

DONE

- Recommend other alternatives STOP
- Recommend only as a containment alternative YIELD

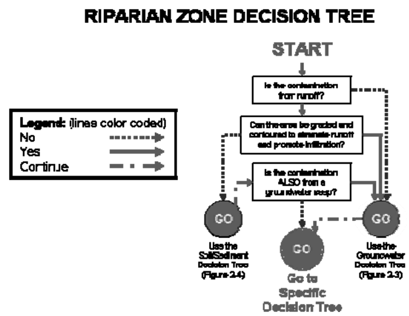
No associated notes.

42

# Riparian Zone Decision Tree

Figure 2-5

Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure




- ▶ Questions based on Site Assessment information to determine applicability to Riparian Transitions
  - Runoff
  - Groundwater Seeps
- ▶ Decision Tree for Riparian Buffers
  - Directed back to either:
    - Groundwater
    - Soil/Sediment

GO

No associated notes.

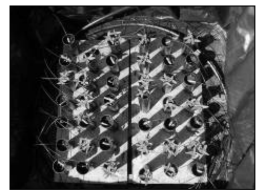
43

# Regulatory Decision Factors

## 2.3.3 Feasibility, Fate & Transport, Treatability Studies

Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

- Demonstrate efficacy of the phytotechnology application
- Address fate and transport questions
- Achieve remedial goals in a reasonable timeframe
- Increase overall confidence
- Prepare for a full scale application (lessons learned → cost savings)



- Typical set up and design
  - Laboratory, greenhouse, or field
  - Hydroponics, potted plants, or test plots
  - Duplicate site conditions as much as possible (temperature, sunlight, precipitation, soil conditions, etc.)
  - Randomized design varying species, concentrations, other factors
  - At least one growth cycle (including dormancy)

No associated notes.

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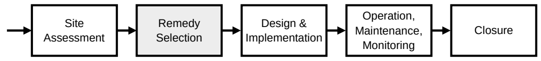
# Stakeholder Decision Factors

Section 2.3.4




- Common factors
  - Aesthetics
  - Operability
  - Future property reuse options
  - Timing
  - Long-term stewardship
  - Sustainability
  - Final site disposition
- See Advantages and Limitations (slides 12-14)

No associated notes.

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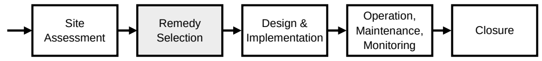
# Economic Decision Factors

Section 2.3.5



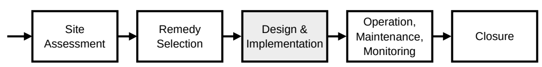

- Project costing
  - Sunk costs
    - 2.3.3 – Feasibility, F&T, Treatability Studies
  - Capital
    - 2.4 – Design & Implementation
  - Engineering and design
    - 2.4 – Design & Implementation
  - Labor
    - 2.4 – D&I and 2.5 – OM&M
  - Operation, maintenance, and monitoring
    - 2.5 – OM&M
- Specific items to consider
  - Groundcover Systems
    - Table 2-5A
  - Tree Systems
    - Table 2-5B
- Comparing phyto costs to other alternatives
  - Quantitative, semi-quantitative, qualitative factors
  - See ITRC ECO-1
    - Table 2-6

No associated notes.

# Design and Implementation

## Safety First!

- ▶ Table 2-7 covers hazards and hazardous conditions typical of phytotechnology systems
  - Biohazards: insects, animals, and plants
  - Overgrowth, felling trees, trimming/cutting, mowing
  - Sampling, fertilizer application, plant waste handling
- ▶ Offers potential solutions
- ▶ Placed initially in section to “design for safety”
  - Plant selection, spacing, accessibility
  - Maintenance, long-term stewardship
  - Medical fitness, allergies




No associated notes.

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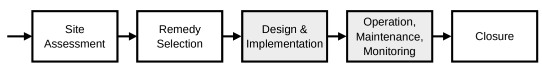
# Design and Implementation

## Modeling (Section 2.4.1)

- Hydrologic loading models: EPIC, HELP
- Water balance (net aquifer storage, S):
  - Complex: $S(\delta h/\delta t) = [\nabla \bullet (Kb\nabla h)] + [P + I - R + q - ET]$
  - Simplified: $ET > P + I - R + q$
- Evapotranspiration, ET:
  - FAO Penman-Monteith (based on meteorological data)
- Phytoextraction (plant uptake) models:
  - $U_{above} = TSCF * T * C$ Transpiration Stream Concentration Factor
  - $U_{root} = RCF * T * C$ Root Concentration Factor
- Attenuation factors, k:
  - Zero-order: $C(t) = C_0 - kt$
  - First-order: $C(t) = C_0 e^{-kt}$




KISS (Keep it simple) Philosophy - Many uncontrolled factors

Erosion/Productivity Impact Calculator
Hydrologic Evaluation of Landfill Performance

Net aquifer storage model:
where S = subsurface storage capacity see Section 2.2.2
h = hydraulic gradient (3-dimensional) (input & output) see Section 2.2.2
K = hydraulic conductivity (3-dimensional) (input & output) see Section 2.2.2
b = aquifer boundary thickness (3-dimensional) see Section 2.3.2.2
t = time
P = precipitation (input) see Section 2.5.2
I = irrigation (input) see Sections 2.5.2 and 2.5.1.1
R = net surface runoff (output) see Sections 2.4.1.1 and 2.5.2
q = other surface water sources or sinks (input or output) see Section 2.2.2
ET = total canopy evapotranspiration* (output) see Sections 2.5.2 and 2.5.3.1
$\nabla$ = partial differential operator (d/dx + d/dy + d/dz)
* ET can be further divided into evaporation (E) and transpiration (T) components.

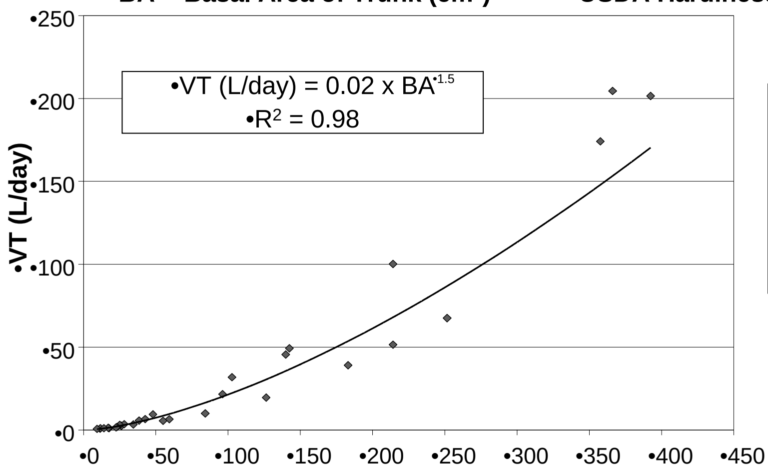
TSCF = Transpiration Stream Concentration Factor
RCF = Root Concentration Factor
T = Transpiration (excluding evaporation)
C = Concentration

# Design and Implementation

Empirical Equations (Figure 2-6)

**VT = Water Usage (L/day)**
**BA = Basal Area of Trunk (cm²)**

**Poplars (*Populus* sp.)**
**USDA Hardiness Zones 5b-6a**




**•Mean Basal Area (cm²)**

Sap Flow Sensors
(covered later)

Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

No associated notes.

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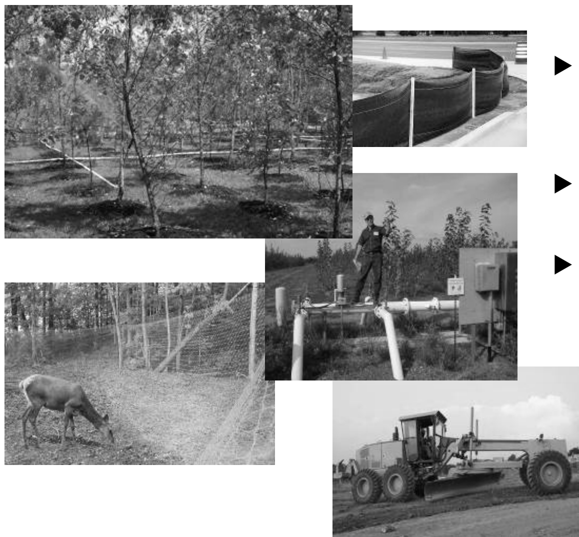
# Design and Implementation

## Infrastructure and Site Preparation (Section 2.4.2)



- Irrigation systems, infiltration control, and storm water management
- Onsite access, fencing, and security
- Soil preparation, amendments, and fertilizers

Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

No associated notes.

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# Design and Implementation

## Realities of Contaminated Sites – “Soil” Quality

- Maintained un-vegetated (spray herbicide)
- High gravel content, fill material
- Old, highly weathered, encrusted, heavy hydrocarbons
- No natural organic matter
- No moisture retention or nutrient content

Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

No associated notes.

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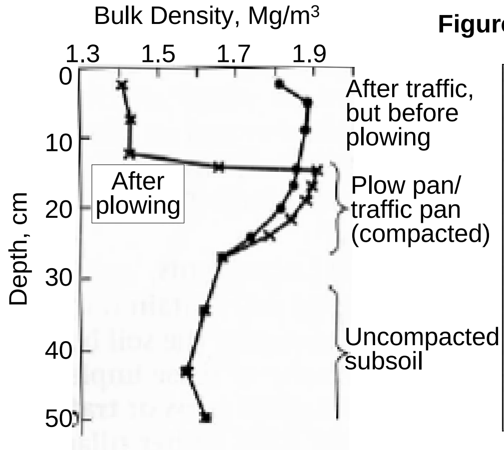
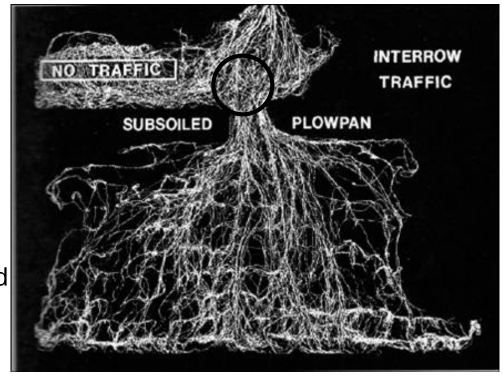
# Design and Implementation

Realities of Contaminated Sites – "Soil" Compaction

**Figure 2-7**




Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

No associated notes.

# Design and Implementation

## Soil Amendments

→ Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

INTERSTATE TECHNOLOGY REGULATORY COUNCIL ITRC

**•Table 2-9 Potential Amendment Remedies for Various Soil Conditions/Growth Needs**

| **Soil Condition or Affect** | **Soil Amendment** |
|---|---|
| General fertility | Balanced (10-10-10) NPK fertilizer, biosolids, sewage sludge |
| Root development/growth | Phosphate fertilizer, ectomycorrhizal fungi |
| Foliar growth | Nitrogen fertilizer |
| Nutrient regulation | Potassium fertilizer |
| Essential metals uptake | Ectomycorrhizal fungi, chelating agents, weak acids |
| Acidity (pH <5) | Lime |
| Alkalinity (pH >9) | Gypsum, sulfur |
| Salinity (EC >2 or 4 mS/cm [a])<br>Sodicity [b] (SAR >12 meq/L) | Gypsum, calcium/magnesium fertilizer (+irrigation) |
| Water holding capacity | Compost / mulch mixed in (see table 2-11) |
| Moisture retention<br>Temperature regulation | Compost / mulch on surface (see table 2-11) |
| Aeration | Earthworms |

[a] The U.S. Department of Agriculture defines water with an Electrical Conductivity (EC) greater than 4.0 mS/cm as saline. The horticulture industry frequently uses a standard of 2 mS/cm to define saline water

[b] Sodium Adsorption Ratio, SAR = Na / ? [(Ca + Mg) / 2] (These values are in meq/L)

• SAR = (Na x 0.043) / ? {[(Ca x 0.05) + (Mg x 0.083)] / 2} (These values are in ppm or mg/L)

No associated notes.

53

# Design and Implementation

## Tables 2-10 and 2-11 – Organic Matter

| Compost | C:N Ratio |
|---|---|
| Manure (Fresh) | 15:1 |
| Legumes (peas etc.) | 15:1 |
| Grass Clippings | 20:1 |
| Manure w/Weeds | 23:1 |
| Weeds (Fresh) | 25:1 |
| Hay (Dry) | 40:1 |
| Leaves (Fresh) | 40:1 |
| Leaves (Dry) | 60:1 |
| Weeds (Dry) | 90:1 |
| Straw, cornstalks | 100:1 |
| Pine Needles | 110:1 |
| Sawdust | 500:1 |
| Wood Chips | 700:1 |

| Target Ratio | C | N | P | K |
|---|---|---|---|---|
| High | 100 | 25 | 10 | 5 |
| Low | 100 | 5 | 2 | 1 |

Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

No associated notes.

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# Design and Implementation

## 2.4.3 Plant Selection, Plant Stock

- Plant selection was initiated during Remedy Selection
- Advantages/disadvantages of different stock
  - Cost, commercial availability, competitive survivability, ease of installation, establishment success, predation, storage and transport
  - Space requirements, planting rates → cost estimation
- Stock selection (commercial availability can be seasonal)
  - Groundcovers
    - Seed, bare-root, plugs, potted stock
  - Tree stands
    - Whips, poles, bare-root, potted, B&B
  - Riparian transitions
    - Any of the above +/- water
    - Wetland indicator status (see Figure 1-12)
- Avoid monocultures
- 10-15% climax species might be included in the initial design
- Planting is typically done in late winter or early spring
  - So order stock at the appropriate time (months in advance)

Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

No associated notes.

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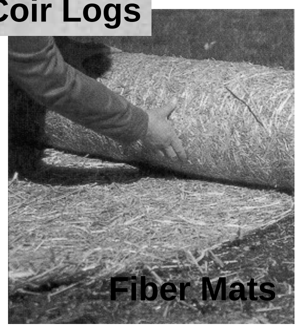
# Design and Implementation

2.4.3 Planting Methods – Groundcovers




Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

No associated notes.

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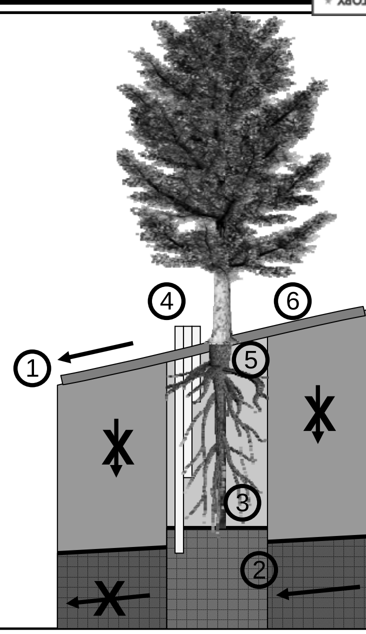
# Design and Implementation

## 2.4.3 Planting Methods – Trees

Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

1. **Contour / Mounding**
2. **Borehole**
3. **Deep Planting (*Salicaceae*)**
4. **Multi-Level Drip Irrigation**
5. **Designed Backfill**
6. **Landscape Tarp**




No associated notes.

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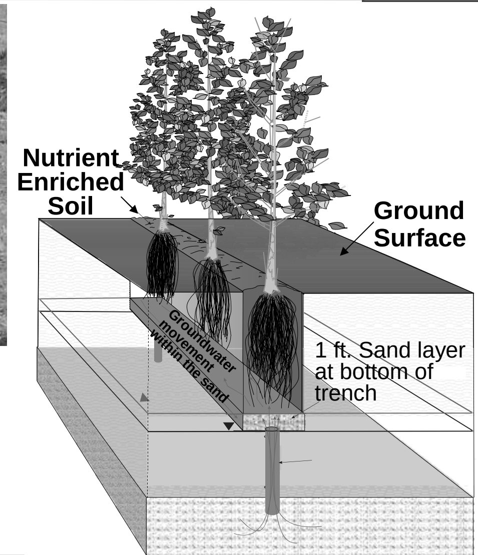
# Design and Implementation

## 2.4.3 Alternative Planting Techniques




- Can be a faster installation
- Requires more backfill (generates more waste?)

Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

No associated notes.

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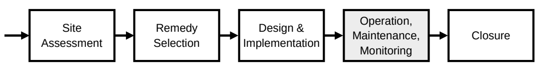
# Operation and Maintenance

## 2.5.1 Maintaining Plant Nutrition

- Generally more important to develop a vigorous root system rather than a healthy canopy; although, the two cannot be separated
- Fertilizing/soil amendments
  - Conditioning guides
    - Tables 2-9, 2-10, 2-11 (slides 52-53)
  - Analysis methods
    - Table 2-12
- Irrigation
  - Target 1 to 2 inches per week, including precipitation




No associated notes.

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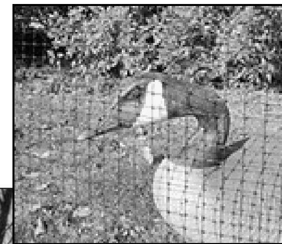
# Operation and Maintenance

## Ensuring Survivability/Sustainability

- If you build it, they will come



Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

No associated notes.

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# Operation and Maintenance

## 2.5.1 Dealing with the Grateful Critters

Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

Electric fence and trunk guards to control deer


**BT *(Bacillus thuringiensis)* spray to control insects**


**Hawk poles and inter-row mowing to control rodents**

No associated notes.

61

# Another O&M Issue

## 2.5.1 Handling / Disposing of Harvested Material


- ▶ Chinese Brake Fern (*Pterris vittata*) – L. Ma, et al., 2001
  - Discovered in Florida (and China)
  - 400 to 1,500 ppm As in site soil
  - 6,800 to 22,000 ppm dw in plant
  - Phytoextracted into living plant as As(III)
  - When harvested, rapidly converts to As(V)

Chinese Demonstration Site

**Arsenic Removal in the Field**

| Sample depth (cm) | Average As conc (mg/kg) | | | Total As depletion | |
|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | mg/kg | % |
| 0-15 | 190 | 182 | 140 | 50 | •26% |
| 15-30 | 278 | 212 | 158 | 120 | •43% |
| 30-60 | 191 | 180 | 169 | 22 | •12% |

→ Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

No associated notes.

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# Monitoring Growth Conditions

## 2.5.2 Terrestrial Growth

- The focus should always remain on the remedial performance of the system rather than just on the aesthetic quality of the surface appearance
- Climate conditions
  - Temperature, humidity, precipitation, wind speed/direction, solar radiation
- Canopy height, trunk girth
  - Some trees can grow 5 to 10 ft per year initially
  - Trunk diameter measured at breast height (4½ ft in the U.S.)


Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

No associated notes.

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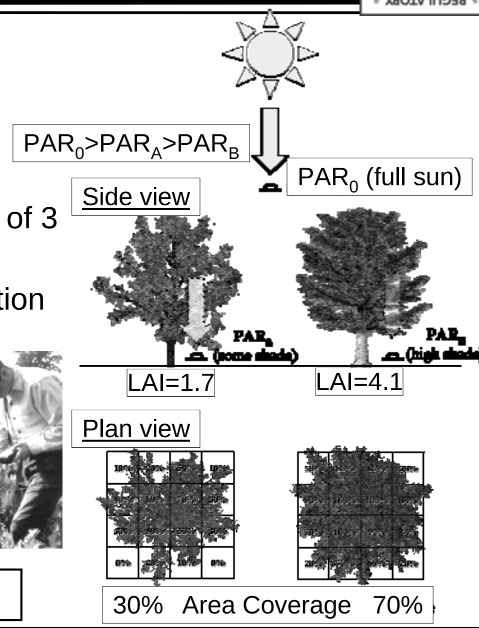
# Monitoring Growth Conditions

Canopy Development (Figure 2-8)

- Canopy closure
  - All solar energy (driving the system) is captured
- Leaf Area Index (LAI)
  - 100% canopy closure → LAI of 3 to 4 (some species 6 to 7)
- Photosynthetically Active Radiation (PAR) sensor
  - 400-700 nm




Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

No associated notes.

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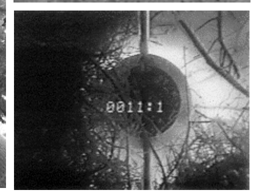
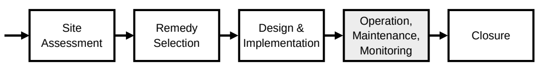
# Monitoring Growth Conditions

## 2.5.2 Root Growth

- 70-80% of the root structure will be within the top 1-2 feet of surface (including tap-rooted species)
- Most root systems (other than wetland species) will not penetrate significantly into a saturated zone
- Methods to investigate
  - Tree dig
  - Down-hole camera
  - Tracers/tracking compounds in cores
  - Isotope ratios: $D_2O/H_2O$ ($\delta D$)



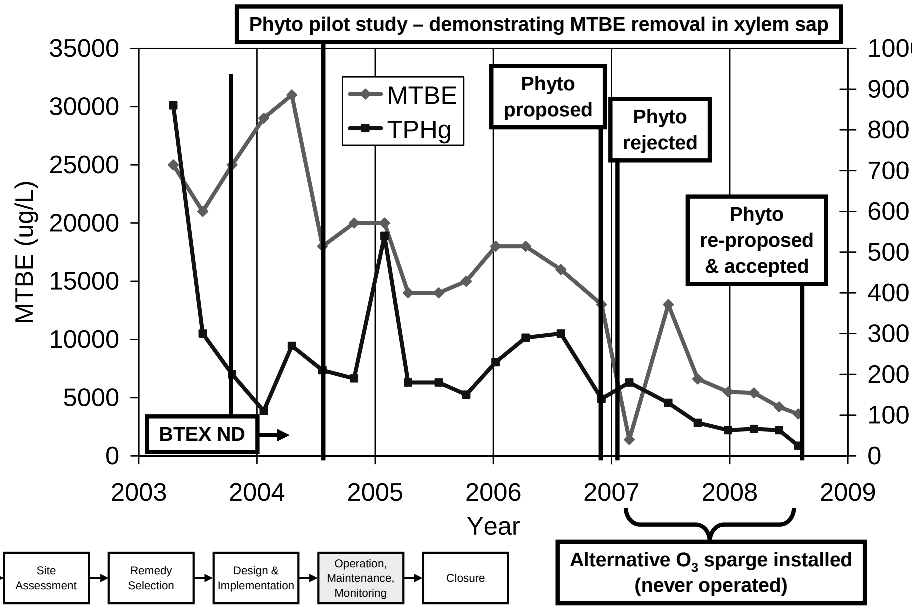

**$\delta D_{vadose}$ -- $\delta D_{xylem}$ -- $\delta D_{GW}$**




No associated notes.

# Monitoring Remediation Performance

2.5.3 Concentration Reduction – Primary Evidence



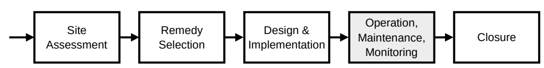

No associated notes.

66

# Monitoring Remediation Performance

## 2.5.3 Other Techniques – Secondary Evidence

- Other monitoring approaches applicable to phyto systems
  - Soil Moisture: lysimeters, tensiometers, etc.
  - Microbiology: PLFA (GC-MS fingerprint), PCR-DGGE (genetic fingerprint)
  - Geochemical Characteristics: temperature, $CO_2$, $O_2$
- Phyto-specific performance monitoring techniques
  - Water usage: sap flow sensors
  - Plant tissue sampling (including trunk coring)
  - Transpiration gas capture/sampling




No associated notes.

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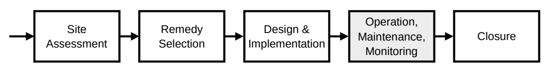
# Long-Term OM&M

## 2.5.4 Contingency Planning

- Triggers to be considered
  - Natural disasters
    - Floods, droughts, hurricanes, wildfires
  - Infestations
    - Disease, predation
  - Operational events
    - Vandalism, malfunctioning support equipment
- Scale and duration
  - Plant resilience
    - A few days, remainder of the season, a season or two to recover
  - 10% to 15% of the initial capital costs should be added as a contingency for replanting in the first 2-3 years
  - Individual plant mortality
    - Natural selection




No associated notes.

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# Closure

## Section 2.6 – Planning Final Land Use Upfront

- Ecological – see ITRC ECO-1
- Recreational – parks, trails, sports facilities, etc.
- Commercial – landscape design


Former Refinery
Now Certified Habitat

Active
Commercial
Retail Site

Former Refinery
Now Golf Facility

Site Assessment → Remedy Selection → Design & Implementation → Operation, Maintenance, Monitoring → Closure

No associated notes.

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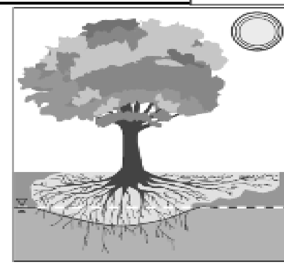
# In Summary

**Phytotechnologies Technical and Regulatory Guidance and Decision Trees**



- Technologies using plants to remediate or contain contaminants in soil, groundwater, surface water, or sediment
- Limitations are known
- Phytotechnologies should be considered a conventional Technology
- The document can be used regardless of the stage of your project

No associated notes.

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# Thank You for Participating

- **2nd question and answer break**
- **Links to additional resources**
  - http://www.clu-in.org/conf/itrc/phyto2/resource.cfm
- **Feedback form – *please* complete**
  - http://www.clu-in.org/conf/itrc/phyto2/feedback.cfm


Need confirmation of your participation today?

Fill out the feedback form and check box for confirmation email.

Links to additional resources:
http://www.clu-in.org/conf/itrc/phyto2/resource.cfm

Your feedback is important – please fill out the form at:
http://www.clu-in.org/conf/itrc/phyto2/feedback.cfm

**The benefits that ITRC offers to state regulators and technology developers, vendors, and consultants include:**

✓Helping regulators build their knowledge base and raise their confidence about new environmental technologies

✓Helping regulators save time and money when evaluating environmental technologies

✓Guiding technology developers in the collection of performance data to satisfy the requirements of multiple states

✓Helping technology vendors avoid the time and expense of conducting duplicative and costly demonstrations

✓Providing a reliable network among members of the environmental community to focus on innovative environmental technologies

**How you can get involved with ITRC:**

✓Join an ITRC Team – with just 10% of your time you can have a positive impact on the regulatory process and acceptance of innovative technologies and approaches

✓Sponsor ITRC's technical team and other activities

✓Use ITRC products and attend training courses

✓Submit proposals for new technical teams and projects