VEGETATED TREATMENT OF VEHICLE WASH SEDIMENTS: DEVELOPMENT OF A DECISION SUPPORT TREE

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ABSTRACT

The design of natural treatment systems that use vegetation is a developing area of research. In order to move this technique from research to practical use, a system to assist potential users in the proper design is needed. This paper will present a decision support tree designed to assist in the planning of a natural treatment system for a contaminated soil, using vegetation. This support tree has the potential to offer the background needed for design rather than requiring the user to possess this background. By using the support tree, persons seeking choices regarding information on the design of a vegetated treatment option can find simple and generalized solutions. The objective of this paper is to show an initial guide for a vegetated treatment option, the decision support tree. The decision support tree will require input from the user. The input would consist of answering a few questions related to the type of contamination, soil, and climate. From this input, the decision support tree will provide a list of plants that would be suited to the site. Future work will include having the output from this decision tree to serve as input to a graphical user interface to further help environmental professionals design vegetated treatment options.

Key words: *phytoremediation, petroleum hydrocarbons, remediation, vegetation, contaminant*

INTRODUCTION

A need exists for a system providing support in the design of a vegetated treatment option for contaminated sites. Potential users of vegetation in treatment system designs have no tool at present to aid in designing the treatment systems. The objective of this paper is to present a simple screening tool to use as an initial guide in evaluating whether vegetation will work for a particular site.

DEFINITIONS

Since not all vegetated treatment options are alike, a few definitions are offered.

- Phytoremediation — the use of vegetation in various engineered treatment options
- Phytotransformation — the process that involves the uptake and metabolism of contaminants
- Rhizosphere bioremediation — degradation of a contaminant due to the increased microbial activity around the root zone (rhizosphere)
- Phytostabilization — the use of vegetation to prevent the migration of contaminants through control of the hydraulic gradient or reinforcing of the soil structure
- Phytoextraction — the use of vegetation to uptake contaminants into their biomass
- Rhizofiltration — the use of vegetation roots to sorb contaminants in place

MAJOR FACTORS INVOLVED IN CHOOSING VEGETATION

Many factors are involved in properly choosing vegetation for use on a contaminated soil, sediment, or water. The first factor considered by the decision tree is regulatory concerns. Depending on individual state regulations, special permission may need to be obtained in order to employ a vegetated remediation solution. The second factor considered is climate. Climate is characterized by a number of individual parameters including precipitation, minimum and maximum temperatures, length of growing season, evaporation potential, drought potential, and flooding potential. In addition to climate parameters, the user may need to consider the ecoregion for *in situ* treatment systems that are to produce an ecologically viable solution.

The next decision factor considered is soil. Soil can also be characterized by a number of different measures including texture, fertility, and pH. The last factor considered is contaminant properties. Properties associated with the contaminant depend on the type of contaminant and the amount of contaminant present. In order to choose the proper type of vegetation, one needs to consider each of these factors and how they interact with each other. Knowing the type of contaminant may limit the types of vegetation that may be available to choose from. Also knowing the factors describing the climate can help choose what type of vegetated treatment options are possible.

QUESTIONNAIRE-BASED DECISION SUPPORT TREE FOR ASSESSING THE USE OF VEGETATION IN A REMEDIATION SYSTEM

The following series of questions comprise the initial guide designed by the researchers, based on the identified factors. Each question is followed by the range of answers allowed and suggested information sources to use in answering the question.

1. Are there any regulations in your area conerning the four natural treatment options?
   Answer: Yes or No.
   Contact State Department of Health and the Environment or equivalent agency. Soil cleanup guidelines for each state are available at http://www.aehs.com/. Use the link to state surveys, and then choose the appropriate state.

2. What is the pH of the soil? Answers: >8, 6-8, or <6. Depending on the pH, a quantity of acceptable vegetation may be limited. Additionally, a recommendation for soil amendments may be made to modify the soil environment to provide a suitable environment for vegetation.
   Soil Testing - pH

3 What is the soil classification on site? Answers: clay, sandy clay, silty clay, clay

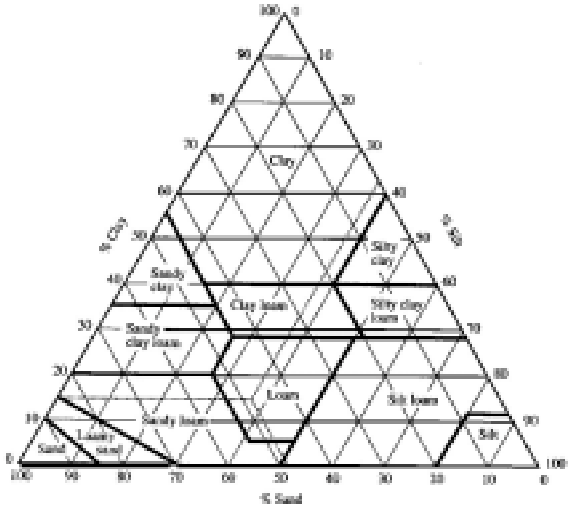

Figure 1. The USDA Soil Texture Triangle (Eweis et al., 1998).

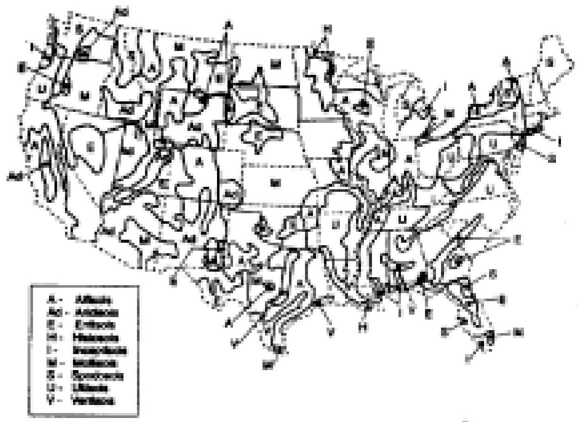

Figure 2. The Soil Orders of the United States (Dragun, 1998).

loam, sandy clay loam, silty clay loam, loam, sandy loam, silt loam, loamy sand, sand, and silt. These soils are classified into three main categories: fine-, medium-, and coarse-textured soils. A fine soil generally contains mainly clays and silts. A medium soil contains a high percentage of sands and some gravel. A coarse soil has a high percentage of sand and gravel. Based on this classification, different plants can be eliminated for consideration.

Soil Testing Results – Texture (Figure 1)

4. Identify the fertility of the soil based on soil orders of the U.S. Using the soil order chart and the following information, a fertility level of low, medium, or high, can be assigned.

   Soil order chart (Figure 2) along with the following descriptions for fertility (Dragun, 1998).

   Alfisol – high
   Andisol – low
   Aridisol – high if sufficient water is present
   Entisol – highly variable, but can be high with adequate fertilization and water
   Histosol – medium to high, especially if drained
   Inceptisol — medium to high
   Mollisol – high
   Oxisol – low, needs heavy fertilization to become marginally productive
   Spodosol – high if sufficient fertilizer is supplied
   Ultisol – medium
   Vertisol – low due to swelling nature of clays in the soil and fine texture

5. Contaminants which might pose a risk (toxicity to plants or humans). Answer: Choose all that apply and use the number of hits to assess the overall toxicity of the soil.

Arsenic > 40 mg/kg
Boron > 3 mg/kg
Cadmium > 15 mg/kg
Chromium(total) > 1000 mg/kg
Copper > 200 mg/kg
Mercury > 20 mg/kg
Nickel > 100 mg/kg
Zinc > 500 mg/kg
Cyanides (total) > 250 mg/kg
Phenols > 20 mg/kg
Sulfates > 2000 mg/kg
Tars (as poly-aromatic hydrocarbons) > 1000 mg/kg
Petroleum products > 100 mg/kg
Site Evaluation

6. What is the depth of the contaminated soil? Answer: < 6 inches, 8 to 12 inches, 15 to 20 inches, and greater than 20 inches. The categories are used to select grasses, garden crops or grasses, shrubs, and trees, respectively.
Site Evaluation

7. What is the depth to groundwater? Answer: < 3 feet, 3 to 8 feet, > 8 feet. If the groundwater table is less than three feet, hydraulic draining of the site might be necessary to reduce the potential for migration of contaminants. A plant type with a high evapotranspirative rate is suggested in this case. For an application with a groundwater table between three and eight feet, there is little risk for migration and should be sufficient water for plant growth. If the water table is greater than eight, irrigation may be necessary for establishing the vegetation.
Site Evaluation

8. How long is the growing season (number of frost-free days)? Answer: number of days. Plants are selected based on the number of frost-free days.
Climate data available at http://www.cdc.noaa.gov/~cas/Climo/polys/states.html.

9. What is the minimum temperature at the site? Answer: a temperature. Plants are selected based on hardiness to low temperatures.
Hardiness map (Figure 3)

10. What is the average annual precipitation at the site? Answer: a numeric value. Plants are selected based on the need for water from precipitation.
Climate data (Figure 4) or the Web site noted in question 8.

11. Rank the probability of drought at the site for the next year. Answer: low, medium, or high. Based on the probability for drought, irrigation may be necessary for adequate plant growth. Also, drought-tolerant species can be selected.

Drought forecasting center at http://enso.unl.edu/ndmc/. You can follow the link entitled drought watch and proceed to drought monitoring. There are other useful links to past drought maps and general historical drought information.

Based on the answers to these questions,

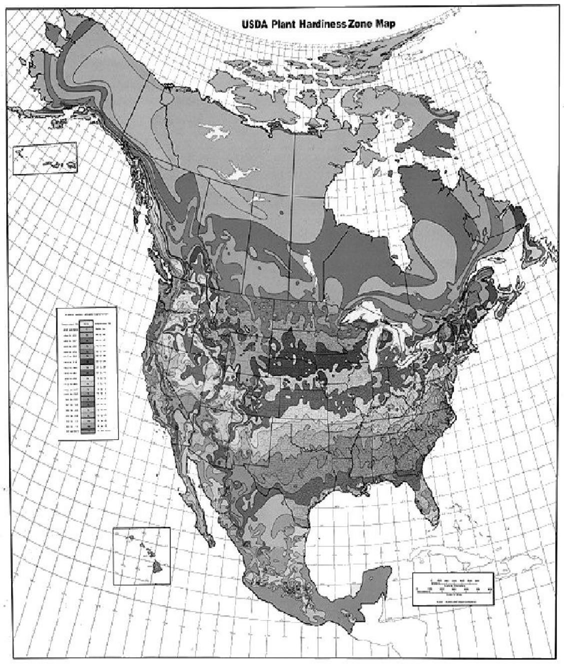

Figure 3. Hardiness Zones in North America (National Arboretum, 1999).

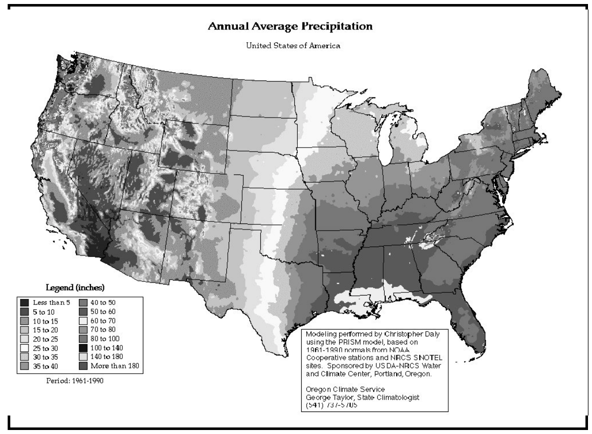

Figure 4. Average Annual Precipitation for the United States (Oregon Climate Service, 2000).

the user can select vegetation from a database. Table 1 shows a portion of a plant database constructed from known information on plants used in remediation studies. Only a small portion of this database is shown in this paper. Please contact the authors for more information on the full database developed for this application. Table 2 shows a summary of data for the Fort Riley vehicle wash pit waste treatment site. Using the data from Table 2 and the questionnaire, the following answers were obtained.

1. Yes, Kansas Department of Health and Environment requires the cleanup of petroleum-contaminated soils above 100 mg/kg.

2. The pH of the contaminated soil is 8. This pH is within the typical range of 6-8; therefore, modifications of the pH aren't necessary. The plant characteristic table lists the following plants, tall fescue, western wheatgrass, smooth brome, Kentucky bluegrass, reed ,canary grass, Bermuda grass, and coon's tail, with a preferred growth pH in the min/max range specified.

3. The characterization of the soil from the site showed that the contaminated soil consisted of 40% sand, 42% silt, and 18% clay, while the native soil from the site consisted of 20% sand, 62% silt, and 18% clay. Therefore, the contaminated soil is considered a loam and the native soil is considered to be a silt loam. These soil types are considered to be medium- to fine-textured soils and this does not disqualify any of the plants from the list in question 2.

4. Based on the location of Fort Riley, the soil order is considered a mollisol. Mollisols are dark in color and have a high fertility. Therefore, no plants are eliminated from the list.

5. Based on the site evaluation and required soil testing, copper, zinc, and sulfate are well below toxic limits. The measurement for total petroleum hydrocarbon (TPH) content was 821 mg/kg, which is above the toxicity limit. With this high level of contamination, the soil would be considered semi-toxic to toxic. Since the contamination at Fort Riley is mainly petroleum wastes, pretreatment will not be required. Higher petroleum levels have been known to affect germination and allowances may need to be taken to safeguard this.

6. The depth of contaminated soil depends on the manner in which the contaminated soil is placed on the native soil. Since the treatment depths at Fort Riley are 45 cm or 18 inches, grasses and/or forbs would be recommended.

7. The depth to the groundwater on the site is >8 feet. This area will not need hydraulic control since the layers are on a hill. Since the depth of contamination is limited and no hydraulic control is needed, trees are not recommended.

Table 1: Plant Characteristics Database.

Name	Type	Life Cycle	Max Precip (in)	Min Temp (F)	Min pH	Min root depth (in)	Min Precip (in)
tall fescue	grass	perennial	55	-38	5	12	24
birdfoot deer vetch	forb	perennial	65	-33	5.5	14	24
red clover	forb	perennial	65	-38	6	12	35
western wheatgrass	grass	perennial	32	-28	4.5	20	10
smooth brome	grass	perennial	45	-33	5.5	12	30
Kentucky bluegrass	grass	perennial	65	-28	5	10	24
Orchard grass	grass	perennial	60	-43	5	12	30
reed canary grass	grass	perennial	65	-33	5.5	14	35
big bluestem	grass	perennial	55	-43	6	20	12
Indian grass	grass	perennial	40	-23	5	24	12
Bermuda grass	grass	perennial	55	12	5.5	14	36
sunflower	forb	Annual	60	52	5.5	8	12
Indian mustard	forb	Annual	80	17	6	6	30
coon's tail	forb	perennial	55	-38	6.2	0	10
white poplar	tree	perennial	55	-43	4.9	24	24
switch grass	grass	perennial	40	-3	4.5	12	20

8. From the National Oceanic and Atmospheric Administration (NOAA) Web site for the Fort Riley, Kansas area, we find that the annual temperature graph shows above-freezing days from April to middle November, or 200 frost-free days. This does not remove any plants from our selected list.

Table 2. Soil Characteristics of Petroleum Hydrocarbon-Contaminated Sediments and Reference. Uncontaminated Soil.

Characteristic	Unit	Central Wash Facility Sediment	Native Soil
Texture			
Sand	%	40	20
Silt	%	42	62
Clay	%	18	18
pH		8	6.4
Organic Matter	%	208	3.8
NH4+	mg/kg	604	6.9
NO3-	mg/kg	501	1.8
Brays P	mg/kg	1	6
Total N	mg/kg	1027	703
Total P	mg/kg	255	173
Sulfate	mg/kg	28.2	3.2
Chloride	mg/kg	4	2
Exchangeable Cations			
K	mg/kg	209	301
Ca	mg/kg	4740	3350
Mg	mg/kg	370	605
Na	mg/kg	38.3	13.2
DTPA Extractable Metals			
Zn	mg/kg	6.6	0.6
Fe	mg/kg	58.2	36.9
Mn	mg/kg	11.3	13.1
Cu	mg/kg	2.2	1.1
CEC	mmol/kg	14.3	28.8

9. The minimum temperature at Fort Riley is --15° F. This would remove Bermuda grass from the selected list 23.

10. The average precipitation at Fort Riley is 33 inches. Based on this information, both western wheatgrass and reed canary grass will be removed from the selected list, if we follow the temperature guidelines strictly. Western wheatgrass could be kept in the list since it has a water requirement close to the anticipated rainfall for the area.

11. Fort Riley is considered to have a low probability of drought, and this would not remove any plants from the selected list.

So the list of possible plants to use in a vegetated treatment option would be tall fescue, smooth brome, Kentucky bluegrass, and coon's tail, with western wheatgrass as an optional species. Any of these recommendations should be confirmed with local extension or other specialists.

CONCLUSIONS

In order for vegetation to be considered as part of a remediation treatment system, a simplified manner to choose the different types of applicable vegetation is needed. By using the designed questionnaire and the referenced data sources, a user can obtain a list of plants that might be applied to an engineered remediation solution. The questions contained in the questionnaire are arranged so that non-technical users can find the answers they need, or they will be directed to the type of data to collect in order to answer the questions. Further work is in progress to create a computerized graphical user interface that encompasses the questions and provides access to resources to answer the questions.

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REFERENCES

Cairney, Tom, 1995. The Re-Use of Contaminated Land: A Handbook of Risk Assessment, John Wiley & Sons, New York, NY.

Dragun, James, 1998. The Soil Chemistry of Hazardous Materials – 2nd Edition, Amherst Scientific Publishers, Amherst, MA.

Eweis, Juana B., Sarina J. Ergas, Daniel P.Y. Chang, and Edward D. Schroeder, 1998. Bioremediation Principles, McGraw-Hill, Inc., New York, NY.

National Arboretum, 1999. USDS Hardiness Zone Map Information, Available on-line at http://www.ars-grin.gov/ars/Beltsville/na/hardines.html.

Oregon Climate Service, 2000. Annual Average Precipitation: United States of America, Available on-line at: http://www.ocs.orst.edu/pub/maps/Precipitation/Total/U.S./us_precip.GIF.