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A review of the impacts and risks for use of native grass, forb, shrub and tree species plantings when used to stabilize and close domestic solid waste landfill caps.

prepared for

The Albany, New York Landfill

by

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INTRODUCTION

This is a technical review of the scientific literature to address the following questions and purposes:

- Can native prairie grasses, wildflowers, forbs and trees be used safely for the final revegetation and stabilization of the Albany landfill cap?
- Will native species grow on geotextile protected clay caps?
- Will these plant species contribute, cause, or exacerbate failure of the geotextile clay cap? If so, by what proven mechanisms?
- Are native plant species equal or superior to stabilize and reduce the risks of failure of geotextile clay caps?
- What are the growth and survival characteristics of native prairie grasses, flowers, shrubs and trees that confirm native species are compatible with landfill cap closure?
- What characteristics of soil and landfill cap management will augment or detract from native species use for landfill cap closures?

OVERVIEW OF SITE CLOSURE PLAN

When landfills are closed with a geotextile clay liner (GCL) and upper barrier protection subsoils to prevent water entry and subsequent mobilization of contaminants, the long-term integrity of the cap system is the paramount concern. Usually, GCLs are covered by a minimum of three or four 6 inch soil lifts that are compacted in place, after clean compacted fill soil of variable thickness was placed on top of the waste. In general, above the waste a lower barrier protection layer of fill soil, often 24” thick, supports a composite plastic liner of 60 mils thickness. On top of the composite liner, a gravel or drainage composite layer is connected to a subsurface drainage system within the cap to move water off the landfill cap safely. Then an upper barrier protection layer (UPBL) of 18 to 24 inches of more permeable soils with an uppermost layer of six inches of humified topsoil completes the cap. Sometimes the geotextile membrane is a bentonite blanket contained between 2 woven geotextile fabric layers rather than a synthetic plastic membrane. The majority of landfill closures then plant the surface to a typical aggressive lawn or roadside grass mix that is not native. When a cap's barrier is either compacted clay or a bentonite blanket, it is important to regulate shrink/swell potential of these soil materials to lower the risk of failure of the clay barrier during cycles of drought and re-wetting. In arid environments, irrigation has been used to control clay shrinkage by moisture and maintain the integrity of the clay layer.

After closure and stabilization, some landfill caps have been converted to open space, parks, even parking lots. Recreational facilities, bicycle paths, walking trails, irrigated lawn, and even floating slab buildings have been installed on thicker caps even those without synthetic or compacted barriers to water penetration, especially in Europe. Presently, North America's largest closed domestic landfill at Fresh Kills, Staten Island, New York is being planned for a succession of land uses that will include the required facilities and infrastructure for recreational uses on a thousand acres of waste footprint of that closed landfill facility. The Penn and Fountain landfill closures on Long Island also feature a close integration with the Jamaica Bay recreational area through the use of specialized soils in the cap above the impermeable layers created to promote the growth of native species. These facilities depart significantly from the typical closure model in three ways: (1) Native species only are used in the vegetation of the caps; the strategy is to promote native species reclamation and retard invasion by alien plant species that prefer rich agronomic soils, (2) Exceptional care has been taken to mimic the chemical and physical qualities of the native subsoil and topsoils of the region in these caps, and (3) Native grasses, forbs, shrubs and trees are the landfill cap vegetation in place of the customary lawn grass.

ASSUMPTIONS

Several assumptions were made during this review as follows:

If native species can be used for site stabilization rather than the common alien grasses this may reduce long term maintenance, obviate any need for irrigation or other annual maintenance and will provide a more attractive successor land use. We assumed it is desirable to naturalize landfills with native vegetation in park-like settings as this will also attract native wildlife that the public deems to be valuable. One explicit goal is to convert perceived public liabilities into valued public assets.

Review of Technical Literature

We summarize the relevant published technical literature and AES experience that addresses the questions and information needs that respond to the questions posed in the introduction.

Demonstration of Regulatory Compliance

This report explores if a native landscape design is consistent with the closure and regulatory intent for this site. The use of native grass, forb, tree, and shrub plantings on caps must provide stabilization and safe conditions before enhancement of the closed site. Regulators require that closure engineering, plant ecological/soil conditions, and ecological restoration strategies are reviewed for appropriateness (e.g. Viessman and Hammer 1985; Northeastern Illinois soil erosion and sedimentation control steering committee 1989; Mariner and Mertz-Irwin 1991; Spooner et al. 1992 etc.) The USEPA often addresses non-point source water quality management (USEPA 1983; Cunningham 1988). In some cases the US Fish and Wildlife Service or state Department of Natural Resources may become involved if there are rare, threatened or endangered species, wetland or watershed issues at a site. The typical regulatory concerns usually includes a point by point discussion of the performance of conventional vs. alternative native planting landscape designs with criteria associated with site closure, to wit:

- **Vegetation shall be promoted on all reconstructed surfaces to minimize wind and water erosion of the final protective covers**.

  Stabilization against wind and water erosion, and protection of the capping system, to prevent exposure of the geomembrane and drainage structure is of primary concern during site planning, design and regulatory reviews. Soil bioengineering using locally adapted native plants create stronger and more stable plantings. Native plants are adapted and grow best under the local conditions of ecological severity and extremes as exist on a clay cap slope or top. Native species have shown the most success in stabilization of extreme slopes and poor substrates during wind and water erosion events and especially during extreme drought. Consequently, natives have been recommended for regional use in stressed growing conditions that include road cuts, landfills, mined lands, and other severely-stressed settings, (Horton 1949; Weaver 1954; Plummer 1970; Johnson et al 1971; USDA Soil Cons. Svs. 1972; Gillick and Scott 1975; Hall and Ludwig 1975; USEPA 1975; Edmunson 1976; Dehgan et al 1977; Bennet et al 1978; Kuenstler et al 1978; Monsen 1978; Leone et al 1979; Schiechtl 1980; Diekelmann and Schuster 1982; Hunt 1983; Shimell 1983; Bowen 1985; Peven 1985; Henderson 1987; Gray and Leiser 1989; Apfelbaum 1991; Mariner and Mertz-Irwin 1991, etc.). The excellent performance of native species under severe drought stress is especially significant because the underdrain layer above the geomembrane below the UPBL restricts the available reserves of soil pore water to only the water storable in the permeable soils of this UPBL layer and whatever topsoil has been applied. Typically, the UPBL soils are permeable silty sands with a modest capacity for water storage (i.e. the field capacity) between precipitation events, typically 1.5 – 2.0 inches per foot. In natural soil profiles, there is a measurable capacity to renew this supply by upward wicking of waters from deep subsoils during droughts. This does not exist in landfill caps because the drainage layer above the geomembrane does not store water and the geomembrane or compacted clay barrier prevents access to any pore waters under this barrier.

Limited end-use opportunities often result from the design criteria for plantings done only to lower the risk of failure of the cap. Recently, a series of projects to design closure plantings for multiple benefits and uses have proceeded in the country, most notably in the boroughs of New York. The recently completed Penn and Fountain projects in Brooklyn and the planned Fresh Kills Lifescape project on Staten Island illustrate the direction of landfill capping and closures in New York State. These regional projects are building on experiences at the St. Johns Landfill in Portland, Oregon and Countryside Landfill in Grayslake, Illinois, all of which have used soil bioengineering and plantings with native grasses, wildflowers, shrubs and trees to achieve site stabilization, improved plant and animal diversity and numerous new recreational end-use opportunities that conventional alien species plantings and standard soil caps do not provide. These and other plantings on high risk sites with steep slopes or severe conditions have very favorable outcomes without loss of the engineering integrity of the design and no environmental or regulatory concerns (Handel 1989; Wong and Yu 1989; AES 2004).

- **Vegetation shall be compatible with the climatic conditions.**

  The use of native grasses, forbs, shrubs and trees for slope stabilization to address the regional climatic swings typical of New York growing seasons provides a very different end product and opportunity set. A closure planting program for the Albany site could use native species best adapted to the high exposure, windswept, and extreme droughty slopes and regional climate (Tables

1 and 2). Allowance for the droughty conditions typical of the rare scrub oak-long-leaf pine association next to the landfill is possible with native species that grow, prosper, and flower under all local conditions. Conventional landfill closure plantings of alien cool season grass species, such as tall fescue (*Festuca elatior*) and Eurasian brome (*Bromus inermis*) actively grow only in spring and fall under cool moist conditions and are dormant or have minimal growth at other times of the year unless irrigated. One consequence of a cool season community that shuts down in droughts of summer is a habitat that is not nearly as attractive to wildlife as compared to native landscapes because food sources, particularly insect populations, tend to collapse under drought in the cool season communities.

The adaptability of native plants to drought, very wet conditions, extreme winter exposures and very poor nutrition is documented thoroughly in hundreds of technical papers (Hilgard 1906; Hursh and Haasis 1931; Biswell 1935; Weaver and Albertson 1936; Albertson and Weaver 1942; Albertson 1943; Weaver and Weaver and Albertson 1944; Partch 1949; Osaki et al. 1998; etc). Native species have much higher tolerance to variable and extreme climatic conditions (Weaver 1954; 1956; and 1968). Weaver's (1968) "Prairie Plants and Their Environment" is a masterful reference that details summaries of fifty years of research on hundreds of native species through out the Midwest including the response of the prairie ecological system to the great drought and severe wet periods. Without equivocation, this study documents the unprecedented tolerance and survivability of many of the native grasses and wildflowers included in the example planting plan lists (Table 1). The studies also document the death and failures of many cool season grasses, including bluegrass (*Poa pratensis*) and brome grass, during drought. Native species are the clear choice for the stressful condition of landfill caps.

- **Vegetation shall require little maintenance.**

Native grasses, forbs, shrubs, and trees not only survive and prosper in inhospitable environments, but they require very little maintenance, compared to cool season plantings especially during later years after establishment (Breyer and Pollard 1980; Duebbert 1981; Diekelmann and Schuster 1982; Mariner and Mertz-Irwin 1991; etc). Some clay-capped landfills require seasonal mowing, noxious weed control and regular fertilization programs to maintain cool season grass stands. Native species stands are not nearly as vulnerable to noxious weed invasions; often, alien weeds establish dense monocultures on landfills planted with cool season grasses (Apfelbaum, personal observations; AES 2004). Native grasses and wildflowers are well-adapted to withstand stress and resist mortality that open landfill surfaces to weed invasions. For example, the major native grasses have a photosynthetic pathway (C4) that conserves water (unlike cool season grasses) and have leaf stomata adapted to conserve water. They also have pubescence and revolute leaf margins that contribute to greater water conservation. They require less energy for cooling, sustained growth and basal metabolic needs (Weaver 1968). These adaptations decrease maintenance needs, such as mowing or irrigation. A typical landfill management for native grass and wildflower plantings is mowing to the height of 6 inches when the vegetation reaches about one foot during the first growing season. This prevents most alien weeds from producing seeds. However, perennial native grasses and flowers are too small to be injured by a 6 inch mowing. No watering or fertilizing is recommended, because this benefits the weedy species. Native perennials are adapted to the natural conditions and require no watering or fertilizer (Larson 1991). During the second growing season mowing to a height of 6 inches should continue if weed species have survived. Since soil disturbance is essential for the weeds to continue to survive, it is only rarely used. Areas vacated by a mature annual weed leaves a disturbed soil from which many weed seeds in the soil can emerge (Larson 1991). After year two, mowing can be conducted but only to control noxious weeds that may be present. Otherwise, direct herbicide treatment on persistent noxious weeds becomes the principal management strategy after the fist few years, but this is needed very rarely in native species plantings.

- **Vegetation shall consist of a diverse mix of native and introduced species that is consistent with the post closure land use.**

A native planting program integrates the best characteristics of quick establishing nonnative cool season annual nurse grasses (e.g. oats (*Avena sativa*) and barley (*Hordeum vulgare*)) with long-lived and durable native species plantings. This combination is proven to accomplish early success and stabilization of the capped landfill slopes and top. It will also provide the rapid amelioration of site conditions required for the success of plantings. The plantings will succeed from quick growing annual cover crops as dominants within several weeks after planting, through a cool season growth phase to succeed into a native plant community dominated by grasses and wildflower. A cool season grass understory with successional natives (e.g. Canada wildrye*, (Elymus canadensis*)) will be retained to provide early spring greenups.

The native species planting strategy provides a quality, diverse landscape and wildlife habitat that will support light recreational uses including a regional greenway trail system integrated with the project site. The high diversity of species used in native landscaping provides a complimentary, interesting, and aesthetically pleasing setting for greenway trails, attractive to native wildlife which improves recreational experiences. The resulting biodiversity of a native-restored site is very important for maintenance of the regionally rare populations of many plants and animals. The native species cap closure planting design is consistent with national proposals for protection and restoration of biological diversity (Beecher 1942; Jacobs 1975; Wilson 1988; etc.). Also, because of the very low maintenance needs of established native plant cover, little disruption of the planting will occur. The potential to disrupt recreational uses is low. Reduced maintenance of the planting during the initial establishment period leads to less soil compaction owing to mowing conventional covers to create a low growing community. Conventional mowing management of the slopes underlain by heavy clay substrates can damage soil profiles, promote weedy vegetation and limit human uses, (e.g. surface soil sheer during mowing vehicle turns, compaction and rutting and potential surface water routing changes [See Goran et al. 1983.]). These problems are reduced markedly in low maintenance native species plantings.

The native plant species recommended for caps have high wildlife food and cover values (See Tables 1, 2.); most native prairie grass and wildflower species have moderate to high wildlife cover and food value. The information used to generate these tables is from personal observations and years of site monitoring of native species and conventionally-planted caps for numerous clients (Apfelbaum, Applied Ecological Services, Inc. 2004, unpublished observations and data) and from a plethora of articles, books, and technical papers on the wildlife value of native grasses and wildflowers. Example information sources are identified in the Bibliography and include: Weaver 1968;

Robel 1981; Diekelmann and Shuster 1982; Dove 1983a, 1983b, 1984a, 1984b Farmland Committee 1985; Henderson 1987; etc).

- **Vegetation shall be tolerant of the outgassing often generated in capped sites.**

Most research projects comparing the vulnerability of plants to landfill out-gas have suggested that native prairie grasses and flowers are more tolerant than cool season grasses (Flower et al 1981; Peven 1985; Card 1992;). However, with well designed clay and geomembrane capping systems, vegetative covers are subjected to little out-gas exposure except near well heads for the recovery of landfill gas. Native species also are often the most tolerant plants to other environmental contaminants including excess heavy metals and insufficient trace elements (Lepper 1978; Kabata-Pendia and Pendia 1984; Peven 1985; Eisler 1990; Arthur et al. 1992).

Studies conducted on out-gas and plant relationships suggest if caps are built to specifications, vegetation establishment, growth and success are unaffected. In poorly capped landfills some plant species have died and failed to provide long-term soil stability (Deuber 1936; Arthur et al 1981). In fact, plant mortalities are used to detect gas leaks on landfills and from gas pipelines (Eyon 1967). Tolerance to gas in the soil relates directly to its composition and concentration, timing of exposures, plant phenology and the presence of other metabolic gases such as oxygen and carbon dioxide as well as toxic gases such as methane and hydrogen sulfide. If seed sources are near, native prairie plants are often the first to invade landfill environments. Some observers have concluded that not only are some native plants tolerant of landfill gasses, but also to other stressful environmental conditions on landfills. (Leonard and Pinckard 1946; Gilman et al 1978; Flower et al. 1978,1981; Gilmanm et al 1981; Morgan and Sullivan 1981; Shimell 1983, etc).

Crook (1992) investigated the feasibility of planting trees on clay-capped landfills and other containment sites. He concluded that planting even trees on sites is unlikely to violate clay caps in an out-gassing environment or over heavily compacted clay caps because most tree species require a soil atmosphere with 18% oxygen or more and die with less than 12% soil oxygen. He identified that carbon dioxide, methane, or ethylene in concentrations of 5-10% or greater in soil voids will kill most trees. Stonell (1986) identified that clay caps can become weakened in drought and that tree roots are capable of drying clays below the moisture content which induces cracking. They found tree roots generally confined to the top 300 mm of soil, but others have suggested that roots can desiccate to soil depths of 700 mm. They recommended that if trees planted on a clay cap, that they only be planted in locations with soil or rooting medium of a minimum 1 meter in thickness. In Britain, the Department of Environment (1984) reports that it is possible to control tree root growth on landfills by maintaining low fertility in deeper soil layers, or by compacting the base layers of final soil cover. Robinson and Handel (1995) showed there is no theoretical or empirical basis to disallow tree plantings on clay-capped sites. They excavated 30 trees and shrubs growing on a clay-lined municipal sanitary landfill invaded by trees for seven years after closure. All trees had shallow roots, including species that grow typically with tap roots. Only occasionally were small feeder roots found in the upper 1 cm of the clay caps. They concluded that thorough compaction of a clay cap created a substrate with material densities well above those roots will penetrate. Compaction alone stopped root growth; mean penetrometer resistance values above 2.0 Mpa control root potential penetration (Hermann 1977; Atkinson and Mace-Dawson 1991; McMichael and Persson 1991; and Atwell 1993). (Glinski and Lipiec 1990; Campbell and O'Sullivan 1991; Bennie 1991; and Bengough 1991). Dobson and Moffat (1995) reached the same conclusions regarding the root growth for trees or shrubs on compacted clay caps. In friable native soils, they found 90% of trees and shrub roots in the upper 0.6 meters of soils, and substantially less on compacted clay caps roots. They also concluded that tree roots and subsequent evapotranspirational water losses are extremely unlikely to be the primary cause of dessiccation cracking in a clay cap owing to their inability to extract more than a few percent of the total moisture held in clays with sufficient density to have the requisite low permeability of 1 x 10^{-7} to 10^{-9} cm/s. Where high density polyethelene liners or mineral materials were used in caps and the upper barrier protection material was compacted to a bulk density of 1.8 grams/cubic centimeter, there was no evidence that tree or other plant roots were able to penetrate. The authors conclude that with proper planning and installation, trees and shrubs may be grown successfully without violating clay cap integrity. In addition they contend that clay capped facilities can be designed to provide more ecologically diverse and valuable vegetation, if this is a discrete goal of closure projects, and is supported by good bioengineering, design, and site examination.

April and Sims (1990) examined the usefulness of providing enhanced treatment of toxic organic chemicals using eight deep rooted prairie grasses (big and little bluestems, indian grass, switch grass, Canada wild rye, side oats grama, western wheat grass and blue grama). This study involved planting prairie grasses on a highly permeable sand top soil over a site with four polycyclic aromatic hydrocarbons (PAHs). The extent of PAH disappearance in vegetated soil was significantly greater than in unvegetated soils. They concluded that where deep soil penetration is desired, these plants can be a low cost, effective, and low maintenance alternative for addressing PAH contaminated soils. They believed increased soil-microbial activity, improved physical and chemical properties of the contaminated soils, and increased the contact between microbes associated with the root and the toxic compounds in the contaminated soils were the primary mechanisms of detoxification.

Native prairie grasses and wildflowers have typically not been used on landfills or clay capped sites. We believe this has occurred because of the simplicity, lower seed cost and convention of using nonnative grasses and clovers in all aspects of re-vegetation associated with disturbed landscapes, especially mined lands and road right-of-ways. The misconception that the root penetration depth or required rooting depth is too deep, has also prevented the use of native plants until recently. This misconception may have led professionals to conclude native plant materials would compromise the clay cap and contribute to its failure. Cool season and native prairie grasses experience different opportunities for root growth and achieve different rooting depths depending on the nature of the substrate in which they grow (Weaver 1968; Bohm 1979; Atkinson and Mackie-Dawson 1991). In loose uncompacted soils both native and alien species may grow roots many meters deep. However, in heavily compacted soils and even where mere inches of topsoil and subsoil occur on impermeable bedrock, cool season and native prairie grasses and forbs will grow but will have poor vertical root development. Under compacted soil conditions, such as on a clay cap, the major difference between these groups of plants is the markedly greater and denser root mass of native plants that increases the ability of these plants to tolerate physiological stresses, such as drought, (Atkinson and Mackie-Dawson 1991) and may contribute to greater cap stability (Browning 1990). A primary focus of much recent research has been on rooting depth and potential violation of the integrity of the landfill cap (Flower et al 1978; Gilman 1979; Leone et al 1979; Stalter 1979; Gilman 1980; Lutton 1982; Gilman et al 1985; Ettala

1987; Attala 1988; Wong and Yu 1989, etc). These studies have generally indicated that root penetration of clay caps does not occur for a number of reasons:

High Compaction of clay substrates impedes root penetration of caps except perhaps in cracks that develop in the caps because of thermal contraction (Andersland and Al-Moussawi 1987).

Prevailing research results suggest that root growth does not represent a threat to clay caps. In fact, a geomembrane system only reinforces resistance to root penetration. Based on studies of how roots direct growth, and how root morphology changes in response to natural soil profile changes, we believe strongly that well compacted clay caps (even without the presence of a geomembrane system) will provide an effective barrier to root penetration. In order to grow, a root pushes through the soil with an extending root tip with a diameter of 0.1 to 3mm. To move through soil, which generally contains pores of 0.002 to 0.2 mm or less, the root grows by turgor (osmotic-hydraulic) pressure. It must therefore push aside soil materials. Consequently, nonporous soils (such as compacted clays (even without a geomembrane barrier) represent a formidable barrier. On engineered clay caps with heavy soil compaction and on compacted mined sites, the lack of woody plant and herbaceous plant growth is related to the inability of roots to penetrate the substrates. Various methods for subsoil ripping and other soil preparation treatments are required to reduce compaction before plant growth will even occur, (Brown et al 1968; Brandshaw and Chadwick 1980; Malcom 1990; Apfelbaum 1991, etc). High Bulk densities in naturally occurring soils ≥ 1.5-1.8 mg/cm^2 retard root growth profoundly. On compacted landfill caps, bulk densities may be much greater and thus would be expected to be an effective barrier to root penetration. Resistance to root growth is also related to the average soil pore sizes. Soils with high bulk density values, especially highly compacted clay substrates, have a very small average soil pore size that restricts root penetration on caps. Resistance to root penetration increases directly in the vicinity of root growth owing to displaced soil materials. This increased soil compaction in the growing region in an already compacted soil environment results in cessation of continued root growth in the direction of increased bulk density. This limits root growth to upper shallow topsoils. Typically, plant root growth is restricted to spreading in these environments.

At the Fresh Kills landfill, research documented that even where thermal expansion related soil cracks formed in the landfill cap, root invasion did not occur for a number of reasons. Apparent impediments to root growth into existing landfill cap cracks were correlated with the layer of anoxic, nutrient poor sand, (drainage layer), probably suffused with methane, carbon dioxide, and other inhibitory gasses. Research found that thin probing taproots might penetrate through breaks or pores in the clay cap but that they would die back rather than increase in length or thickness. In fact, if gases are present in the fractured soils in sufficient concentration, root growth even above the clay cap is inhibited. Rather than the plant challenging the integrity of the clay cap, in a typical clay cap, plants cannot overcome these stressful conditions. Since clay caps are also nutrient poor, but inhibit nutrient uptake (owing to clay colloid binding capacity [Brady 1974]), root growth into caps should be minimal. Depth of root growth has demonstrated that root architecture is almost always controlled by the nature of the substrate in which the plants grow. Deep rooting plants in native soils have been well documented (Meinzer 1927; Coile 1951; Kreutzer 1961; Bibelriether 1966; Sutton 1969,1991; Russell 1973; Savill 1976; Foster 1993), while extreme shallow-surficial roots have been documented in compacted or geologically constrained soils.

Heavily compacted soils have been altered by tillage and subsoil loosening to achieve substantially greater rooting depth, plant production, increased soil porosity, and increased hydraulic conductivity (Harrison, Cameron and McLaren 1994). These techniques are the opposite of those used on GCC and GCL capped sites. These and other studies have demonstrated benefits of subsoil loosening and tillage are reversible by engineered compaction, altering soil textural composition, and by altering the chemistry of soil (CEC, pH, etc.). Native uncompacted soils and subsoils compared to engineered soil cap systems, will sustain very different plant growth by the same plant species. Root growth and above ground plant growth are significantly diminished in compacted soils, whether native or engineered.

- **Temporary erosion control measures, including but not limited to mulch straw, netting and chemical soil stabilizers, shall be undertaken while vegetation is being established.**

  The site stabilization strategy employed on most clay capping projects includes use of short lived and quickly establishing annual cover crops and a mulching system involving several options. The annual plants are seeded simultaneously with biennial and long and short lived perennial species. With this planting strategy, all species are potentially seeded simultaneously and will consequently respond to conditions for germination as they become suitable. Because of the seasonal nature for planting native prairie grass and flower species, if slopes are readied for final planting but the season is not proper for planting natives, then a cover cropping system is included. Once established, the native prairie seeded will be no-till drilled. The drilling of the native species seeds will be conducted directly into the established cover crop grass to cause minimal soil disruption.

  This same planting strategy was employed in the reclamation and revegetation of mined lands in Wisconsin; it has been very successful in the extreme environment of high waste rock dumps which have the same risk of erosion and plant exposure as on regional landfill tops and slopes, especially south and west aspect slopes (Ludwig and Apfelbaum, In Press; Burris and Apfelbaum 1992).

The mulching system can include erosion netting, erosion bats, and straw checks and blown straw if and where necessary to maximize erosion control. If hydromulching does occur, a tackifier such as Guar Gum is a very effective soil and mulch stabilizer. This tackifier produces a wet-resistant surface which reduces soil saturation, potential effects of slope failure from mass wasting and solufluction, and greatly reduces erosion of mulch and seed.

- **What evidence exists for root penetration of Geotextile clay caps and liners?**

Investigations of root penetration of GCL's and GCC's were done in lab and field settings. Melchior (1997) found lawn grasses, and weeds with fine roots (≤1 mm diameter) did penetrate bentonite mats during the first year where the GCC were installed over gravel and sand underdrainage layers. During year two, some liginified larger roots were also found to grow into the GCC. They speculated that if larger diameter lignified roots died and decomposed, then the remaining void could form open flow channels through the matting. However, they were not able to demonstrate this to occur in either field or laboratory experiments. The GCC was found to crack during drought but reseal during rehydration. Fine roots of grasses and weeds grew during wet periods, and ceased during dry down periods when the GCC developed vertical and horizontal "cracks". Under the experimental conditions, they found fine roots to grow completely through the mat in the first growing season.

They concluded that there is still a lack of convincing evidence and documented proof that bentonite mats (GCC and GCL) will work in caps. Use must be considered on a case by case basis. They also stated that new GCLs made with two bentonite layers divided by a middle geotextile, and prehydrated bentonite with organic additives, will improve performance. The lack of drying of the bentonite layer does not prevent root penetration by lawn grasses and other plants. They also identified a problem with GCC mats that did lead to failures that were completely unrelated to plant materials. They found that sodium in the sodium bentonite clay used in the GCC was prone to fail if irrigated with moderate to high carbonate waters containing calcium and magnesium. Then, the sodium cations were replaced by the calcium or magnesium; these chemical reactions reduced resealability of the GCC after modest or severe drought.

Technical Data Sheets for Geosynthetic clay lines (GCL's) (__Unpublished CETCO TR-310) found during a "tank scale" study that primary tap roots of weeds did not penetrate the GCL. Roots traveled directly downward, then turned 90 degrees upon encountering the GCL, and grew parallel to the surface of the GCL. They concluded the woven geotextile covering was "apparently sufficiently tightly knit to prevent penetration by tap roots". The study did find that fine root hairs that branched from the tap root were able to penetrate the GCL. The geotextile did not appear stretched or damaged by root penetration. They also tested permeability of the penetrated mat and found even with penetration that the permeability of the penetrated mat was consistent with "virgin" unpenetrated GCL.

Kargbo, Fanning, Inyang, and Duell (1993) have cautioned that the permeability of GCC and GCL's will increase in clay soils with the potential to produce acid sulfate. Where the potential for acid sulfate generation at the substrate interface with the underside of the GCC/GCL exists, this can increase permeability of the liner, result in mortality of vegetation exposed to strong acids, and enhance erosion risks of the cap. They suggest testing substrates that the GCC/GCL will be bedded on to ensure acid sulfate generation will not occur. Mobilization of metals from soils is typically associated with pyritic and other sulfur bearing minerals; under irrigated or excessively wet aerobic conditions in the near surface environment, the production of free sulfuric acid can occur. This study found that where clay acidification occurred below the GCC or GCL, topsoils failed to support the plant species applied as stabilization cover. Non-native species, such as lawn grasses, roadside, highway grass and clover mixes were especially intolerant of acidification. In fact, some of the most tolerant plant species included the native grasses such as little bluestem (*Andropogon scoparius*). Considerable work has been done on Geotextile Clay liners beneath landfilled materials. These studies have focused narrowly on the permeability of the liners and the chemical influence of leachates on liner performance and efficiency (Hoeks, Glas, Hofkamp and Ryhiner 1987).

Koerner and Daniel (1992) summarized the performance of all of the major categories of capping systems including GCC and GCL caps. They rated each cap and closure performance under environmental factors that complicate their design and influence success. Included were temperature extremes (freezing and thawing to significant depths), wet/dry cycles, potential for penetration by plant roots, burrowing animals (e.g. worms, insects, etc.), total differential settlement caused by compression of the waste or foundation soils, temporary or permanent surcharge by stockpiling materials, downslope slippage or creep, vehicle movements that drive over caps, wind and water erosion, deformation caused by earthquakes, long-term moisture changes if water moves in or out of wastes, and alterations caused by gas derived from volatile or decomposable wastes. Ratings presented in this paper suggested that GCL and GCC designs are marginally acceptable, or not recommended for use if any of these variables presents a threat to the barrier layer material. In combination with a geomembrane, a two layer barrier system (GCL and GCC) is acceptable and recommended as feasible and cost effective. This study also suggests that a single-layered geomembrane system will out-perform a geosynthetic clay liner and a clay capped liner system and may cost less in the long-term.

Bowerman and Redente (1998) document that few capping and liner systems employed anywhere in the world can escape biointrusions of the protective barriers especially in arid regions. They state that mice, ants, ground squirrels, prairie dogs, some plants pose a threat to barrier integrity and waste isolation and that engineered caps have been designed without consideration of the ecological principals and processes, which can be crucial to their performance. They stress that incorporation of ecological processes into barrier design is essential to lower risk of failure (Waugh and Richardson 1997). These authors summarize some newer capping technologies that include thicker caps, use of slow release herbicides to prevent root growth and other new ideas (Wing and Gee 1994).

CONCLUSIONS:

Biointrusion into a Geotextile clay cap or liner lacking the 24” fill soil and drainage layer above a GCL can occur, but such cap designs are now illegal for domestic waste landfills. Plants can violate a poorly compacted cap or if otherwise not constructed to specifications. Plant and animals have influenced water infiltration, channeling, soil pore space, aeration, physical and chemical properties, and the community eventually established on native soils and reclaimed mine sites. There is no reason to believe they cannot do the same on capped sites (Ellison 1946; Edwards and Lofty 1978, 1980; Kalisz and Stone 1984; Nyhan 1989; Sejkora 1989; Blom 1990; Blom et al. 1994; Gonzales et al. 1995). Compacted subsoils can be a temporal and spatial barrier to cap penetration. Some authors question the longevity of capping systems not designed with ecological processes in mind, contending that biointrusion is likely and perhaps inevitable. However, at the Albany landfill site, the probability of cap failure by root penetration is very remote; a far greater risk is likely if poor construction practices are allowed. While the chemical environment of the Albany cap including subsoil pH and acidification tendencies could be deleterious to GCC and GCL integrity, that is equally unlikely owing to soil chemistry.

Plant growth on the Albany cap will occur during wet periods then decrease or cease as cap desiccation occurs. Root die back can occur often during periods of desiccation. Roots will not grow into cracks, because root growth stops and cracking occur simultaneously during desiccation. During rehydration, the GCL reseals before plant root growth can respond to rewetting. Native vegetation has substantially higher rates of precipitation interception compared to the usually specified lawn species for the typical cap site. These interception rates substantially reduce the total annual water available for infiltration or runoff (Apfelbaum in preparation; Weaver 1968). Native vegetation is substantially more drought tolerant and survives extreme drought much better compared to alien cool season grass species.

Lawn grass species need fertilizer and irrigation in capped settings; native vegetation does not need these amendments, nor regular maintenance; this reduces maintenance costs. Fertilizer and irrigation water chemistries can alter the chemistry and physical integrity of the GCC or GCL altering pH, calcium-sodium ratios in the bentonite clay of the GCC or GCL. Native vegetation which does not require fertilization or irrigation, does not present these risks.

If acidification problems manifest on this site, native species are substantially more adaptable. Natives can endure greater changes in substrate chemistry than alien species. An acidified soil may resist replanting.

Native prairie vegetation has higher root mass densities than cool season nonnative lawn grasses; this allows prairie vegetation to provide greater soil stabilization. Native plants are especially resistant to downhill creep and mass soil movement. This can be important on landfills where material settlement occurs routinely.

Lawn and cool season grasses can encourage the presence of burrowing mammals, because no root structure is present in the subsoils. Prairie vegetation provides more above ground plant mass that is habitat cover. This attracts animals that utilize surface cover, rather than encourage burrowing species. Some mammals (e.g. woodchucks *Marmota monax*) burrow regardless of the above ground vegetation cover, especially along slope breaks and on side slopes. For these species, greater resistance to burrowing owing to the dense root masses below ground of native plants are important.

All vegetation covers on capped sites, even highly maintained lawn associations, will be invaded by weedy plants (Robinson and Handel 1993). This occurs rapidly if sources for bird and mammal disseminated seeds are present, or seeds/propagules can wash in during floods. Many weedy species are most invasive into highly maintained low diversity plantings such as lawns in contrast to native species plantings with dense root masses, and competitive growth forms. The current site design does not take into account this potential and tendency for site invasion and potential biointrusion.

Many native plant species representing low to tall, spring-fall flowering, unique colorization and texture are available for use in the final cover planting on the Albany site (Tables1A, 1B and 2). Some areas on the site may also be suitable for planting of trees and shrubs.

The depth of top soil and fill soil types envisioned for the Albany landfill suggests only fine roots will penetrate the GCL. These are very small diameter non-lignified roots. The capacity of the GCL to reseal will not be compromised by these roots and root hairs. The probability of GCL failure from penetration is very very low! All prairie plants, including shrubs and trees (Tables 1A, 1B, 2) are expected to be compatible with the proposed capping system.

References Cited and Bibliography

Adapting Woody Species and Planting Techniques to Landfill Conditions, Field and Laboratory Investigations, Municipal Environmental Research Lab. USDC (NTIS) PB80-122617, By Cook Coil, New Brunswick, NJ
Allen, Durward L., 1967, The Life of Prairies and Plaints. McGraw-Hill Book Company, New York.

Ahern, J. 1990. Hydrobioengineering Techniques for Streambank Stabilization and Reclamation With New England Application, Illinois Environmental Protection Agency (IEPA). 1983. The Illinois Water Quality Management Plan. Springfield, Illinois. IEPA/WPC/82-012.

Anacostia Restoration Team. 1992. Watershed Restoration Sourcebook. Collected papers presented at the conference; "Restoring Our Home River: Water Quality and Habitat in the Anacostia", held November 6 and 7, 1991 in College Park, MD. Department of Environmental programs, Metropolitan Washington, Council of Governments.

Andersland, O.B. and H.M. Al-Moussawi. 1987. Crack formation in soil landfill covers due to thermal contraction. Waste Management and Research 5:445.

Apfelbaum, S.I. and C. Sams. 1987. Ecology and Management of Reed Canary Grass (*Phalaris arundinacea l.*). Natural Areas Journal 7(2):69-74.

Apfelbaum, S.I. 1985. Cattail (Typha spp.) Management. Natural Areas Journal 5(3):9-17.

Apfelbaum, S.I. 1991. Evaluation of the condition and potential for restoration success in the mitigation wetlands created by the Illinois State

Tollway Highway Authority. Submitted to: Envirodyne Engineers, Inc., Chicago, IL and Illinois Tollway Highway Authority. 137 pp.

Apfelbaum, S.I. (In preparation) Unpublished data analysis and manuscripts. A. Hydrological data from 1886-1904. From: United States of America vs. Economy Power and Light, Case 2525, U.S. Circuit Court of Appeals, 7th Circuit, 1908. Daily stage data at Riverside, IL, 1886-1904 and state discharge calibration data.

Aplet, Jo Anne H. and W. David Conn. The use of completed landfills. University of California, Los Angeles, CA. School of Architecture & Urban Planning.

Aprill, W., and R.C. Simms. 1990. Evaluation of the use of Prairie Grasses for Stimulant Polycyclic Aromatic Hydrocarbon Treatment in Soil. Chemosphere 20(1-2):253-266.

Arthur, M.A., G. Rubin, R.E. Schneider, and L.H. Weinstein. 1992. Uptake and Accumulation of Selenium by Terrestrial Plants Growing on a Coal fly landfill. 3. Forbs and grasses. Pergamon Press. 11(9):1301-1306.

Arthur, M.A., G. Rubin, and P.D. Woodbury. 1992. Uptake and Accumulation of Selenium by Terrestrial Plants growing on a Coal Fly Ash Landfill. 2. Forage and Root Crops. Pergamon Press. 11(9):1289-1299.

Arthur, J.J., I.A. Leone, and F.B. Flower. 1981. Flooding and landfill gas effects on red and sugar maples. Journal of Environmental Quality. 10(4):431-433.

Atkinson, D., and L.A. Mackie-Dawson. 1991. Root growth: Methods of Measurement. Pages 447-509 in K.A. Smith and C.E. Mullins, editors, Soil Analysis. Marcel Dekker, Inc., New York.

Atwell, B.J. 1993. Response of roots to mechanical impedance. Environmental and Experimental Botany 33:27-40.

Baver, L.D., W.H. Gardner, and W.R. Gardner. Soil Physics, John Wiley and Sons, Inc., New York, 1972.

Beecher, W.J. 1942. Nesting birds and the vegetation substrates. Chicago Ornithol. Soc. Chicago, IL 69 pp.

Bengough, A.G. 1991. The penetrometer in relation to mechanical resistance to root growth. Pages 431-445 in K. A. Smith and C. E. Mullins (eds.), Soil analysis. Marcel Dekker, New York.

Bennet, O.L., E.T. Mathias, W.H. Armiger, and J.N. Jones, Jr. 1978. Plant materials and their requirements for growth in humid regions. In: Schaller, Frank W., and Sutton, Paul, Eds. Reclamation of drastically distrubed lands. Amer. Soc. Of Agron., Crop Sci. Soc. Of Amer., Soil Sci. Soc. Of Amer., Madison, Wisc. Ch. 16, pp 285-306.

Bennie, A.T.P. 1991. Growth and mechanical impedance. In: Y. Waisel, A. Eshel, and U. Kafkafi (eds.), Plant roots, The hidden half. Marcel Dekker, New York. Pp. 393-414

Benson, C.H. and D.E. Daniel. 1990. Water Content-Density Criteria for Compacted Soil Liners. Journal of Geotechnical Engineering, 116(12):

1811-1830.

Best, K.F., J. Looman and J.B. Campbell. 1971. Prairie Grasses Identified and Described by Vegetative Characters. Pub #1413, Canada Dept. of Agriculture.

Beyer, W.M. 1990. Evaluating Soil Contamination. U.S. Fish and Wildlife Service, Washington, DC. Biological Report 90(2). 25 pp.

Bibelriether, H. 1966. Root Development of Some Tree Species in Relation to Soil Properties. Allgemeine Forst und Zeitschrift 21, 805-818.

Blom, P.E. 1990. Potential impacts on radioactive waste disposal situations by the harvester ant, Pogonomyrmex salinus Olsen (Hymenoptera: Formicidae). M.S. thesis. Univ. of Idaho, Moscow.

Blom, P.E., and J.B. Johnson. 1991. Concentrations of Cs and Co in nests of the harvester ant, Pogonomyrmex salinus, and associated soils near nuclear reactor waste disposal ponds. Am Midl. Nat. 126:140-151.

Blumer, K. 1990. Why Use Natives Anyway? Reprinted from L.I. Native Plants for Landscaping: A Source Book.

Bohm, W. 1979. Methods of Studying Root Systems. Springer-Verlag, New York, 199 pp.

Bowen, R. 1985. Seeding Specifications: Native Grass and Associated Prairie Seed Mixes for the St. Paul District. St. Paul District, Corps of Engineers. St. Paul, MN 87 pp.

Bowerman, A.G. and E.F. Redente. 1998. Biointrusion of Protective Barriers at Hazardous Waste Sites. Journal of Environmental Quality. 27(3):625-632; 49 ref.

Bowles, M.L. and S.I. Apfelbaum. 1987. A report to the Illinois endangered species protection board on the population status, ecology, and management needs of the heart-leaved (*Plantago cordata*) at the Mackinaw River recreation area, Tazewell County, Illinois. 32 pp. + figures, tables, appendices.

Bradshaw, A.D. and M.J. Chadwick. 1980. The restoration of land. University of California Press. Berkeley, California. 317 pp.

Brady, N.C. The Nature and Properties of Soils. 8th Edition, MacMillan Publishing Co., Inc., N.Y., 1974.

Breyer, D. and G.L. Pollard. 1980. Native grass establishment techniques for wildlife habitat or pastures. U.S.D.A., S.C.S. Agronomy Note No. 19. St. Paul. 7pp.

Brown, D., R.G. Hallman, C.R. Lee., J.G. Skogerboe, K. Eskew, R.A. Price, N.R. Page, M. Clar. R. Kort, and H. Hopkins. 1986. Reclamation and vegetation restoration of problem soils and disturbed lands. Noves Data Corporation. Park Ridge, NJ. 560 pp.

Browing, J.S. III. 1990. Landfill cap stability. The Journal of Resource Management and Technology 18:21.

Buckley, G.P. (ed.). 1989. Biological habitat reconstruction. Belhaven Press. London 363 pp.

Bushwick, N., H. Hiemstra, and S. Brichford (ed.). 1986. Cooperating for Clean Water: Case Studies of Agricultural Nonpoint Source Pollution Control in the Great Lakes States. NASDA Research Foundation farmland Project, Washington, D.C. 140 pages.

Campbell, D.J., and M.F. O'Sullivan. 1991. The cone penetrometer in relation to trafficability, compaction, and tillage. Pages 399-427 in K.A. Smith and C.E. Mullins (eds.), Soil analysis. Marcel Dekker, New York.

Card, G.B. Development on and adjacent to landfill. 1992. Journal of the Institution of Water and Environmental Management 6(3):362.

Chan, Franklin J., Harris, Richard W., and Leiser, Andrew T. (1971). Direct seeding woody plants in the landscape. AXT-n27, Agr. Ext. Serv., Univ. of Calif., Berkeley (Reprinted 1979 as leaflet 2577). 12 pp.

Chaney, R.L. Crop and Food Chain Effects of Toxic Elements in Sludges and Effluents. In Proc, on Recycling Municipal Sludges and Effluents on Land. Nat. Assoc. State Univ. and Land Grant Colleges. EPA and USDA Workshop. Champaign, IL, pp. 129-141.

Clevenger, T.E. 1990. Use of Sequential Extraction to Evaluate the Heavy Metals in Mining Wastes. Water, Air, and Soil Pollution 50:3-4, 241-154; 24 ref.

Coile, T.S. 1951. Review of "Larsen, L., Lull, N.W. & Frank, B. Some Fundamental Plant soil water relations in Watershed Management.

USDA Forest Service, Mimeo Journal of Forestry 49:921-923.

Cornelius, D.R. 1946. Establishment of some true prairie species following reseeding. Ecology. 27:1-12.

Crook, C.S. 1992. The Feasibility of Tree Planting on Landfill Containment Sites. Arboricultural Journal. 16(3): 229-241; 34 ref.

Cross, D.H., and K.L. Fleming. 1989. Control of Phragmites or Common Reed. U.S. Fish and Wildlife Service, Washington, DC. Fish and Wildlife Leaflet 13(4.12). 5 pp.

Cunningham, P.A. 1988. Nonpoint source impacts on aquatic life: literature review. Washington, D.C. Monitoring and Data Support Division, Office of Water Regulations and States.

Dane County Regional Planning Commission. 1976. Solid Waste Management Plan, Dane County, Wisconsin.

DeGraff, R.M. and G.M. Whitman. 1979. Trees, shrubs and vines for attracting birds. Univ. of Mass. Press. Amherst. 194 pp.

Dehgan, Bijan, Tucker, John M., and Takher, Balbir S. (1977). Propagation and culture of new species of drought-tolerant plants for highways. Final report FHWA-CA-77-2 (NTIS PB 273-477). Dept. of Botany, U.C. Davis (for Calif. Dept of Trans.). 168 pp.

Design and Construction of Covers for Solid Waste Landfills, Municipal Environmental Research Lab., Office of Research & Development, USEPA, (EPA-600/2-79-165) 8/1979

Deuber, C.G. 1936. Effects on trees of an illuminating gas in the soil. Plant Physiology. 11:401-412.

Dickerson, J., T. Kelsey and R. Godfrey. The Use of Warm Season Grasses for Revegetating Sands and Gravels in New Hampshire, Vermont, and New York. USDA-SCS.

Diekelmann, J. and R. Schuster. 1982. Natural Landscaping, Designing with Native Plant Communities. McGraw-Hill Book Company, New York.

Dobson, M.D. and A.J. Moffat. 1993a. The Potential for Woodland Establishment on Landfill Sites. London, U.K.: HMSO

Dobson, M.D. and A.J. Moffat. 1993b. Should trees be planted on capped landfills? Waste Planning 7:30-32.

Dobson, M.D. and A.J. Moffat. 1995. A real-evaluation of objections to tree planting on containment landfills. Waste Management and Research, 13(6) 579-600.

Doren, R.F. and L.D. Whiteaker. 1991. The exotic Pest Plant Council. Restoration and Management Notes 9:129-31.

Dosskey, M.G., D.C. Adriano, C.E. Murphy, and J.C. Corey. 1991. Effectiveness of a slow-release herbicide system for control of root intrusions into buried hazardous waste. Hazard. Waste Hazard Mater. 4:293-301.

Douglas, A.J. 1989. Annotated bibliography of economic literature on wetlands. U.S. Fish Wildl. Serv. Biol. Rep. 89(19). 67 pages.

Dove, L.E. 1983b. Feeding birds in winter. Urban Wildlife Manager's Notebook – 3. Supplement to Urban wildlife News. Vol. Vii(3). National Institute for Urban Wildlife, Columbia, MD.

Dove, L.E. 1984a. Housing for nesting birds. Urban Wildlife Manager's Notebook #4. Supplement to Urban Wildlife News. VII(4). National Institute for Urban Wildlife, Columbia, MD.

Dove, L.E. 1984b. Natural landscaping – meadows. Urban Wildlife Manager's notebook – 5 Supplement to Urban Wildlife News, Vol. VIII(1). National Institute for Urban Wildlife, Columbia, MD. 5 pp.

Drake, L.D. 1980. Erosion control with prairie grasses in Iowa strip-mine reclamation. Proceedings of the Seventh North American Prairie Conference. Springfield, MO: Southwest Missouri State University. pp. 189-198.

Duebbert, H.F., E.T. Jacobson, K.F. Hiiggins, and E.B. Podoll. 1981. Establishment of seeded grasslands for wildlife habitat in the prairie pothole region. U.S.D.I., F.W.S. Sp. Scientific Rpt. - Wildlife No. 234. Washington. 21 pp.

Duell, R.W., I.A. Leone, and F.B. Flower. 1986. Effect of landfill gases on soil and vegetation, Pollution Engineering.

Dunne, T. and L.B. Leopold. 1979. Water in environmental planning. W.H. Freeman and Company. 818 pp.

Edmunson, George C. 1976. Plant materials study. A search for drought-tolerant plant materials for erosion control, re-vegetation, and landscaping along California highways. Final Report No. USDASCS L PMC-1. USDA SCS, Davis, Calif. (to State of Calif. Dept. of Trans., Sacramento, Calif.) 257 pp.

Edwards, C.A., and J.R. Lofty. 1978. The influence of arthropods and earthworms upon root growth of direct drilled ceareals. J. Appl. Ecol. 15:789-795.

Edwards, C.A., and J.R. Lofty. 1980. Effects of earthworm inoculation upon the root growth of direct drilled cereals. J. Appl. Ecol. 17:533-543.

Eisler, R. 1990. Boron Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. U.S. Fish and Wildlife Service, Washington, DC. Biological Report 85(1.20). 32 pp.

Ellison, L. 1946. The pocket gopher in relation to soil erosion on mountain range. Ecology 27:101-114.

<u>Environmental Enhancement at the Hackensack Meadowlands: Developing Protocols for the Restoration of Native Plant Communities on New Jersey Landfills</u>, A proposal to the Schmann Fund, By Steven Handel, RUTGERS University 10/89

Etherington, J.R. 1982. <u>Environment and Plant Ecology</u>. John Wiley & Sons, NY. 487 pp.

Ettala, M.O. 1987. Influence of irrigation with leachate on biomass production and evapotranspiration on a sanitary landfill. Aqua Fennica 17:69-86.

Ettala, M.O. 1988. Short-rotation tree plantations at sanitary landfills. Waste Management and Research 6:29-302.

Eynon, S.B. 1967. Current vegetation leakage survey techniques. Gas Age 134(4):38-41.

Farmland Committee – DNR. 1985. Woody cover plantings for wildlife. MN DNR. St. Paul. 16 pp.

Farquhar, G.J. and F.A. Rovers. 1973. Gas production during refuse decomposition. Water, Air, and Soil Pollution 2(4):483-495.

Flower, F.B., I.A. Leone, J.J. Arthur. 1981. Flooding and landfill gas effects on red and sugar maples. Journal of Environmental Quality 10 (4):431.

Flower F.B., I.A. Leone, E.F. Gilman, and J.J. Arthur. 1978. A Study of Vegetation Problems Associated with Refuse Landfills. EPA-600/2-78-094. 129 pp.

Flower, F.B., E.F. Gilman and I.A. Leone. 1981. Landfill gas, what it does to trees and how it's injurious effects may be prevented. J. of Arboriculture 7(2):43-52.

Forster, A. 1993. Landfill Capping Review. An Assessment of Current Practices and Performance Within the United Kingdom, the Rest of Europe and the United States. Department of the Environment Contract Report No. PECD 7/10/251. London, U.K.

Foxx, T.S., G.D. Tierney, and J.M. Williams. 1984a. Rooting depths of plants on low-level waste disposal sites. Rep. LA-10254-MS. Los Alamos Natl. Lab., Los Alamos, NM.

Foxx, T.S., G.D. Tierney, and J.M. Williams. 1984b. Rooting depths of plants relative to biological and environmental factors. Rep. LA-10253-MS. Los Alamos Natl. Lab., Los Alamos. NM.

Frischknecht, N.C. 1978. Use of shrubs for mined land reclamation and wildlife habitat. Proc. Workshop on Reclamation for Wildlife Habitat. Ecology Consultants, Inc., Fort Collins, Colo. 14 pp.

Gilbertson, M. (ed.) 1989. Proceedings of the Workshop on Cause-Effect Linkages held March 28-30, 1989 in Chicago, IL. International Joint Commission, Windsor, Ontario.

Gill, J.D. and W.M. Healy. 1974. Shrubs and vines for northeastern wildlife. NE Forest Exp Sta. Upper Darby, PA. 180 pp

Gillick, T. and D.B. Scott. 1975. Buffer strips and the protection of fishery resources; an economic analysis. Washington Department of Natural Resources. DNR Report.

Gilman, E. 1989. Tree Root Depth Relative to Landfill Tolerance, Horticulture Science, University of Florida.

Gilman, E. F., I.A. Leone, and F.B. Flower. 1978. Screening of species and planting techniques for suitability in vegetating completed sanitary refuse landfills. Proceedings of the First Annual Conf. Of Applied

Research and Practice on Municipal and Industrial Waste. Madison, WI. Sept. 10-13, 1978. Pp. 707-724.

Gilman, E.F. 1979. Screening of woody species and planting techniques for suitability in vegetating completed sanitary refuse landfills. Master's thesis. Graduate Program in Plant Pathology, Rutgers University, New Brunswick, New Jersey.

Gilman, E.F. 1980. Determining the adaptability of woody species, planting techniques and the critical factors for re-vegetating completed refuse landfill sites. Doctoral thesis. Graduate Program in Plant Pathology, Rutgers University, New Brunswick, New Jersey.

Gilman, E.F., F.B. Flower, and I.A. Leone. 1985. Standardized procedures for planting vegetation on completed landfills. Waste Management and Research 3:65-80.

Gilman, E. F., I.A. Leone, and F.B. Flower. 1982. Influence of soil gas contamination on tree root growth. Plant and Soil 65:3-10.

Gilman, E. F., I.A. Leone, and F.B. Flower. 1981. Vertical root distribution of American basswood in sanitary landfill soil. Forest Science 27(4):725-729.

Gilman, E. F., I.A. Leone, and F.B. Flower. 1981b. The adaptability of 19 woody species in vegetating a former sanitary landfill. Forest Science 27(1):13-18.

Gilman, E.F. Establishing Grass, Shrubs and Trees on Completed Sanitary Landfills. Department of Plant Science and Technology Greensboro, North Carolina A & T State University.

Glinski, J. and J. Lipiec. 1990. Soil physical conditions and plant roots. CRC Press, Boca Raton, FL, 250 pp.

Goldsmith, W. and L. Bestmann. An Overview of Bioengineering for Shore Protection. Proceedings of Conference XXII, International Erosion Control Association 1992.

Gonzales, G.J., M.T. Saladen, and T.E. Hakonson. 1995. Effects of pocket gopher burrowing on Cesium-133 distribution on engineered test plots. J. Environ. Qual. 24:1056-1062.

Goran, W.D., L.L. Radke, and W.D. Severinghaus. An Overview of the Ecological Effects of Tracked Vehicles on Major U.S. Army Installations, Technical Report N-142/ADA126694 (U.S. Army Construction

Engineering Research Laboratory (USA-CERL), 1983.)

Gray, H.D. and T.A. Leiser. 1989. Biotechnical Slope Protection and Erosion Control. Krieger Publishing Company, Malabar, FL. 271 pp.

Greig-Smith, P. 1957. Quantitative Plant Ecology. New York: Academic Press Inc. 198 pp.

Gross, D. Section of Landfill Set Aside for Native Plants. Staten Island Advance. 12.22.91.

Gruchow, P. 1985. Journal of a Prairie Year. U of MN Press, Mpls.

Hakonson, T.E. 1986. Evaluation of geologic materials to limit biological intrusion into low-level radioactive waste disposal sites. Rep. LA-10286-MS. Los Alamos Natl. Lab., Los Alamos, NM.

Hall, V.L. and J.D. Ludwig. (1975). Evaluation of potential use of vegetation for erosion abatement along the Great Lakes shoreline. Misc. Paper 7-75. Coastal Eng. Res. Ctr., U.S. Army Corps of Eng., Ft. Belvoir, Va.

Handel, Steven N., Ph.D. and George Robinson, Ph.D. Restoring a Northeast Coastal Forest Community on the Fresh Kills Landfill: Survival, Growth and Recruitment of Trees and Shrubs in an Experimental Plantation. (A Report to the City of New York Department of Sanitation, Waste Management and Facilities Development). Department of Biological Sciences Rutgers, The State University of N.J.

Handel, S.N., G.R. Robinson, W.F.J Parsons, J.H. Mattei. 1997. Restoration of Woody Plants to Capped Landfills: Root Dynamics in an Engineered Soil. Restoration Ecology F:2, 178-186; 22 ref.

Handel, Steven N., Ph.D. and George Robinson, Ph.D. Ecological Interactions Along a Slope Gradient. Rutgers University, State of N.J.
Handel, Steve and George Robinson. Ecological Theory Behind the Basic Concept of Habitat Islands (A Narrative). Biology Department, Rutgers University.

Hardell, J.A. 1980. Response of prairie species planted on iron ore tailings under different fertilization levels. Master's Thesis, Department of Landscape Architecture, University of Wisconsin – Madison.

Harrison, D.F., K.C. Cameron, and R.G. McLaren. 1994. Effects of Subsoil Loosening on Soil Physical Properties, Plant Root Growth, and

Pasture Yield. New Zealand Journal of Agricultural Research 37(4): 559-567; 37 ref.

Harwood, J.J., S.R. Koirtyohann, and C.J. Schmitt. 1987. Effects of Cover Materials on Leaching of Constituents from Dolomitic Lead Mine Tailings. Water, Air and Soil Pollution. 34: 1, 31-43; 1 gig., 9 tab.: 29 ref.

Henderson, C.L. 1987. Landscaping for Wildlife. Minnesota Department of Natural Resources.

Hengst, G.E. 1982. The response of native prairie species to alternative fertilization application during second and third growing seasons on iron ore tailings. Master's Thesis, Department of Landscape Architecture, University of Wisconsin – Madison.

Hermann, R.K. 1977. Growth and production of tree roots: A review. Pages 7-28 in J.K. Marshall (eds), The below-ground ecosystem: A synthesis of plant-associated processes. Range Science Department Science Series No. 26, Colorado State University, Fort Collins. Colorado.

Hilgard, E.W. 1906. Soils, their Formation, Properties, Composition, and Relations to Climate and Plant Growth in the Humid and Arid Regions. New York, The Macmillan Co.

Hillel, D. 1980. Fundamental of Soil Physics. Academic Press, Inc. San Diego, CA 413 pp

Hoeks, J, H. Glas, J. Hofkamp, and A.H. Ryhiner. 1987. Bentonite Liners for Isolation of Waste Disposal Sites. Technical-Bulletins, Institute for Land and Water Management Research, Netherlands. No. 61, 13 pp., 9 fig., 4 tab.

Horton, Jerome S. 1949. Trees and shrubs for erosion control in

Southern California mountains. Calif. Div. For. In coop. With Calif. For. And Range Exp. Sta. (now Pacific Southwest For. And Range Exp. Sta.) USDA For. Svc. 77 pp.

Hunt, L.J., A.W. For, M.C. Landin, and B.R. Wells. 1978. Upland habitat development with dredged material: Engineering and plant propagation. Tech. Report DS-78-17. U.S. Army Eng. Waterways Exp. Sta., Env. Lab., Vicksburg, Miss.

Hunt, T.C. 1983. Vegetative stabilization of a taconite tailings basin in Wisconsin. Master's thesis, Department of Landscape Architecture, University of Wisconsin – Madison. 93 pp.

Illinois Environmental Protection Agency (IEPA). 1988a. Assessment of nonpoint source impacts on Illinois water resources. Illinois Environmental Protection Agency, Division of Water Pollution Control, Springfield, IL. 113 pages.

Illinois Environmental Protection Agency (IEPA). 1988b. Illinois' nonpoint source management program report. Division of Water Pollution Control, Springfield, IL. 111 pages.

Jacobs, J. 1975. Diversity, Stability, and Maturity in Ecosystems Influenced by Human Activities. In Concepts in Ecology, W.H. van Dobben and R.H. Lowe-McConnel, editors. Dr. W.J.B.V. Publishers, The Hague. pp 187-207.

Johnson, A.G., D.B. White, M.H. Smithberg, and L.C. Snyder. 1971. Development of Ground covers for highway slopes. Final Report-1971. Dept. of Hort. Sci., Univ. of Minn. For U.S. Dept. of Trans., Fed. Highway Admin., Minn. Highway Dept., and Minn. Local Road Res. Board. 55 pp.

Johnson, J.B. and P.E. Blom. 1995. Studies on the effectiveness of biobarriers to prevent harvester ant excavation. P. 93-96. In T.D. Reynolds and R.C. Morris (ed.) Environmental Science and Research Foundation Annual Tech. Rep. ESRF-007 Environmental Science and Research Foundation. Idaho Falls, ID.

Kabata-Pendias, A. and H. Pendia. 1984. Trace Elements in Soils and Plants. CRC Press, Inc., Baton Raton, FL. 315 pp.

Kalisz, P.J., and E.L. Stone. 1984. Soil mixing by scarab beetles and pocket gophers in north-central Florida. Soil Sci. Soc. Am. J. 48:169-172.

Kargbo, D.M., D.S. Fanning, H.I. Inyang, and R.W. Duell. 1993. Environmental significance of acid sulfate "clays" as waste covers. Environ.-Geol. 22(3):218-226.

Kaufmann, R. 1970. Hydrology of solid waste disposal sites in Madison, Wisconsin. PhD Thesis, Geology and Geophysics, University of Wisconsin. 361 pp.

Kelling, K.A., P.E. Fixen, E.E. Schulte, E.A. Liegel, and C.R. Simson. 1981. Soil Test Recommendations: For Field, Vegetable and Fruit Crops. University of Wisconsin-Extension, Madison, WI. Pamphlet A2809. 30 pp.

Kelsey, P.D. and R.G. Hootman. 1991. Deicing Salt Dispersion and Effects on Vegetation Along Highways. A Case Study: Deicing Salt Deposition on the Morton Arboretum. The Morton Arboretum, Lisle, IL. 48 pp.
Koerner, R.M. and D.E. Daniel. Better Cover-Ups. (Civil Engineering 9ASCE) CEWRA9, Vol. 62, No. 5, p 55-57, May 1992. 1 fig, 2 tab, 1992.

Knutson, P.L. 1977. Planting guidelines for marsh development and bank stabilization. Coastal Eng. Tech. Aid No. 77-3. U.S. Army Corps of Eng. Fort Belvoir, VA. 22 pp.

Kraayenoord, C.W.S. Van. 1968. Poplars and willows in New Zealand with particular reference to their use in erosion control. Int. Poplar Commission, 13th Session, Montreal. Canada.

Kraebel, C.J. 1936. Erosion control on mountain roads. Circ. 380. USDA, Washington, D.C. 44 pp.

Kreutzer, K. 1961. Root Development of Young Forest Trees on Pseudo-gley Soils. Forstwissen-schaftliches Centralblatt 80: 356-392.

Kuenstler, W. F., D.S. Henry, and S.A. Sanders. 1978. Warm season grass establishment on mine spoil in Kentucky. Proceedings of the Sixth North American Prairie Conference, Ohio State University. pp 202-206.

Kusler, J.and M. Kentula, (editors). 1989. Wetland Creation and Restoration: The status of the Science. Vol. II. U.S. Environmental Protection Agency, EPA/600/3-89-038. 172 pp.

Landfill Gas, What it Does to Trees and How its Injurious Effects May be Prevented, Journal of Aboriculture (Volume 7 #2 2/81)

Landfill Restoration-Boro Presidents Project, (S.I., NY), by Bill Young, RLA & J. Mclaughlin, Hort.

Leeper, G.W. 1978. Managing the heavy metals on the land. Marcel Dekker, Inc., NY. 121 pp.

Leone, I.A., F.B. Flower, E.F. Gilman, and J.J. Arthur. 1979. Adapting Woody Species and Planting Techniques to Landfill Conditions. EPA-600/2-79-128. 134 pp.

Levin, S.A., M.A. Harwell, J.R. Kelly, and K.D. Kimball, editors. 1989. Ecotoxicology: problems and approaches. Springer-Verlag, NY.

Lobry de Bruyn, L.A., and A.J. Conacher. 1990. The role of termites and ants in soil modification: A review. Aust. J. Soil Res. 28:55-93.

Lutton, R.J. 1982. Evaluating cover systems for solid and hazardous waste. US Environmental Protection Agency. Office of Solid Waste and Emergency Response. Manual SW-867 (revised).

Madsen, J. 1982. Where the Sky Began, Land of the Tallgrass Prairie. Houghton Mifflin Company, Boston.

Mansell, Robert S. and S.W. McCallister. 1992. Evaluation of soil top-cover systems to minimize infiltration into a sanitary landfill: A Case Study. Environmental-Geology and Water Sciences 20(2):139-151.

Malcom, C.V. 1990. Rehabilitation agronomy-guidelines for revegetating degraded land. Proceedings of the Ecological Society of Australia 16:551-556.

Mariner, R.D. and L. Mertz-Irwin. 1991. Landscaping techniques and materials for Illinois stream corridors and wetland edges. Illinois Department of Energy and Natural Resources, Office of Research and Planning, Springfield, IL 111 pp.

McAtee, W.L. 1947. Distribution of seeds by birds. American Midland Naturalist 38:214-223.

McConnell, M.J. 1986. Old Field vegetation height and the dispersal pattern of bird-disseminated woody plants. Bulletin of the Torrey Botanical Club 113:6-11.

McKenzie, D.H., L.L. Caldwell, C.E. Cushing, R. Harry, W.E. Kennedy Jr., M.A. Simmons, J.K. Soldat, and B. Swartzman. 1982. Relevance of biotic pathways to the long-term regulation of nuclear waste disposal. Rep. NUREG/CR-2675. PNL-4241. Vol. 1, Vol. 6. Pacific Northwest Lab., Richland, WA.

McMichael, B.L. and H. Persson (eds.). 1991. Plant roots and their environment. Elsevier, Amsterdam.

Meinzer, O.E. 1927. Plants as Indicators of Groundwater. U.S. Geological Survey Water Supply Paper No. 577. U.S.A.

Melchior, S. 1997. In situ studies on the performance of landfill caps. Land Contamination and Reclamation 5:209-216.

Mitsch, W.J. and J.G. Gosselink. 1986. Wetlands. Van Nostrand Reinhold Company, NY. 539 pp.

Molz, F.J. and V.D. Browning. 1977. Effect of vegetation on landfill stabilization. Ground Water 15(6):409-415.

Monsen, S.B. and A. P. Plummer. 1978. Plants and treatment for revegetation of disturbed sites in the intermountain area. In: Wright, Robert A. (Ed.). The reclamation of disturbed arid lands. Univ. New Mexico Press. Albuquerque, NM. Pp. 155-173.

Morgan, W.L. and P.L. Sullivan. 1981. A sturdy of the revegetative capabilities of selected grasses grown on sanitary landfills. Proceedings of the Fourth Annual Madison Conf. Of Applied Research and Practice on Municipal and Industri8al Waste. Madison, WI. Sept. 28-30, 1981.

Morrison, D.G. 1981. Use of prairie vegetation on disturbed sites. Transportation Research Record 822: Landscape and Environmental Design. Wash. DC.: National Academy of Science. pp. 10-17.

Northeastern Illinois Soil Erosion and Sedimentation Control Steering Committee. Procedures and Standards for Urban Soil Erosion and Sedimentation Control in Illinois. Northeastern Illinois Soil Erosion and Sedimentation Control Steering Committee, Lisle. IL.

Noyd, R.K., F.L. Pfleger (a), M.R. Norland, and M.J. Sadowsky. 1995. Native Prairie Grasses and Microbial Community Responses to Reclamation of Taconite Iron Ore Tailing. Canadian Journal of Botany 73(10):1645-1654.

Noyes, H.A. 1914. The effect on plant growth of saturating a soil with carbon dioxide. Science 40:792.

Nyhan, J.W. 1989. Development of Technology for the long-term stabilization and closure of shallow land burial sites in semiarid environments. Rep. LA-1128-MS. Los Alamos Natl. Lab., Los Alamos. NM.

Nyhan, J.W., T.E. Hakonson, and B.J. Drennon. 1990. A water balance study of two landfill cover designs for semiarid regions. Journal of Environmental Quality 19(2):281-288.

Oweis, I.S., G. Dakes, T. Marturano, and R. Wierer, 1994. Soil cover success. Civ. Eng. 64:58-59.

Osaki, M., T. Watanabe, T. Ishizawa, C. Nilnond, T. Nuyim, C. Sittibush, and T. Tadana. 1998. Nutritional characteristics in leaves of native plants grown in acid sulfate, peat, sandy podzolic, and saline soils distributed in Peninsular Thailand. Plant and Soil 201(2):175-182.

Partch, M.L. 1949. Habitat Studies of Soil Moisture in Relation to Plants and Plant Communities. Unpublished Ph.D. Dissertation, Univ. of Wisconsin.

Plass, William T. 1975. An evaluation of trees and shrubs for planting surface-mine spoils. USDA For. Svc. Res. Paper NE-317. N.E. For. Exp. Sta., Upper Darby, Pa.

Plummer, A.P. 1970. Plants for revegetation of roadcuts and other disturbed or eroded areas. Intermountain Region Range Improvement Notes 15(1). USDA For. Svc. Intermountain For. And Range Exp. Sta. 8 pp.

Preston, Jr. J. Richard. 1989. North American Trees. Iowa State University Press. Ames. 407 pp.

Proceedings of the Symposium on Using Municipal and Agricultural Waste for the Production of Horticultural Crops. Hort. Science, 15(2):159-178, 1980.

Raelson, J.V. and G.W. McKee. 1982. Measurement of Plant Cover to Evaluate Revegetation Success. Agronomy Series 67. Dept. of Agron., Penn. St. Univ. 45 pp.

Rehder, A. 1954. Manual of cultivated trees and shrubs hardy in North America. The Macmillan Co., N.Y. 996 pp.

Reynolds, T.D. 1990. Effectiveness of three natural bio-barriers in reducing root intrusion by four semi-arid plant species. Health Phys. 59: 849-952.

Robel, R.J. and N.G. Browning. 1981. Comparative use of woody plantings by non-game birds in Kansas. Wild. Soc. Bull. 9(2):141-148.

Robertson and Bracewell. 1976. Rapid representative sampling of soil gases and their determination by mass spectrometry. Journal of Soil Science 30:681-689.

Robinson, G.R. and S.N. Handel. 1993. Forest restoration on a closed landfill: rapid addition of new species by bird dispersal. Conservation

Biology 7(2):271-278.

Robinson, G.R. and S.N. Handel. 1995. Woody plant roots fail to penetrate a clay-lines landfill: management implications. Environ. Manage. 19(1):57-64.

Robinson, G.R. and S.N. Handel. 1995. Woody plant roots fail to penetrate and clay-lined landfill: management implications. Environmental Management 19(1):57-64.

Robinson, G., S. Handel, V.R. Schmalhofer. Survival, Reproduction and Recruitment of Woody Plants After 14 Years on a Reforested Landfill, RUTGERS University.

Rock, H.W. 1972. Prairie Propagation Handbook. Boerner Botanical Gardens, Milwaukee. 60 pp.

Rogers, L.E. and R.J. Lavigne. 1974. Environmental effects of western harvester ant on the shortgrass priarie. Environ. Entomol. 3:994-997.

Roseboom, D., T. Hill, J. Rodsater, and A. Felsot. 1990. Stream yields from agricultural chemicals and feedlot runoff from an Illinois watershed. ILENR/RE-WR-90/11. Illinois Department of Energy and Natural Resources, Office of Research and Planning, Sprinfield, IL 133 pages.

Rosendahl, Carl O., 1928, (reprinted 1970). Trees and Shrubs of the Upper Midwest. U of MN Press, Mpls.

Russell, E.W. 1973. Soil Conditions and Plant Growth. 10th Edition. London, U.K.: Longman.

Russell, R.S. 1977. Plant Root Systems. Their Function and Interaction with the Soil. London, U.K.: McGraw-Hill Book Co. Ltd.

Sauer, J.R. and S. Driege, editors. 1990. Survey Designs and Statistical Methods for the Estimation of Avian Population Trends. Biological Report 90(1). U.S. Fish and Wildlife Service, Washington, DC. 166 pp.

Savill, P.S. 1976. The effects of drainage and ploughing of surface water gleys on rooting and wind throw of sitka spruce in Northern Ireland. Forestry 49:133-141.

Schiechtl, H. 1980. Bioengineering for land re-reclamation and conservation. Univ. of Alberta Press. Edmonton, Alberta. 400 pp.

Schneider, S. and R. Campbell (eds.) 1991. Cause-Effect linkages II Symposium Abstracts. Conference Held September 27-28, 1991 at Grand Traverse Resort, Traverse City, Michigan, Michigan Audubon Society.

Schwarzmeier, J. 1972. Competitional aspects of prairie restoration in the early stages. In Zimmerman ed. Proceedings of the Second Midwest Prairie Conference. University of Wisconsin. 242 pp.

Sejkora, K.J. 1989. Influence of pocket gophers on water erosion and surface hydrology. Ph.D. Dissertation. Colorado State Univ., Fort Collins, CO.

Shantz, H.L. 1927. Drought resistance and soil moisture. Ecology 8: 145-157.

Shetron, S.G. and D.A. Carroll. 1977. Performance of trees and shrubs on metallic mine mill wastes. Jour. Of Soil and Water Cons. 32(5):222-225.

Shimell, P. 1983. Wise planting improves landfill ecology. World Wastes. Pp. 38-41.

Significance of Landfill Gases on Soil and Vegetative Covers, Haz Pro Proceedings, 2.13.86, Manuscript Published 4/86 RUTGERS

Singer, M.J. and D.N. Munns. 1987. Soils: An Introduction. Macmillian Publishing Company, NY. 492 pp.

Skeel-Virginia A. and D.J. Gibson. 1996. Physiological Performance of Andropogon Gerardii, Panicum Virgatum, and Sorghastrum Nutans on Reclaimed Mine Spoil. Restoration Ecology 4(4): 355-367.

Smith, K.A. 1977. Gas chromatographic analysis of the soil atmosphere. In: Giddings, J.C., ed. Advances in Chromatography. Vol. 15. New York: Marcel Dekker Inc. 331 pp.

Soil Gas Problems for Wood Plants Growing on Former Refuse Landfills, NJ Agricultural Experiment Station, New Brunswick, NJ – by Leone & Flower.

Solid Waste Management. 1973. From refuse heap to botanic garden. 16(8):215-219.

Spooner, J., R.L. Huffman, D.E. Line, J.A. Gale, G.D. Jennings, S.W. Coffey, J.A. Arnold, L. Wyatt, D.L. Osmond, and S.K. Haseeb. 1992. Fate and effects of pollutants. Water Environment Research 64(4):503-514.

Stalter, R. 1984. The plant communities on four landfill sites. New York City, New York. Proceedings of the Annual Meetings. Northeastern Weed Science Society 38:64-71

Standardized Procedures for Planting Vegetation on Landfills, Municipal Environmental Research Lab., Office of Research and Development (USEPA-600/S2-83-055)

Sutton, R.F. 1969. Form and Development of Conifer Root Systems. Commonwealth Agricultural Bureau Technical Communication No. 7. Wallingford, U.K.

Sutton, R.F. 1991. Soil Properties and Root Development in Forest Trees: A Review. Forestry Canada, Ontario Region, Information Report O-X-413.

Swenson, S.B. 1930. Winter feeding of birds. Fins, feathers, and fur. (81):8-13.

The Adaptability of 19 Woody Species in Vegetating a Former Sanitary Landfill, Forest Science (Volume 27 - #1 1981)

The Impacts of Root Growth on the Performance of Bentomat, Colloid Environmental Technologies Company, 1350 W. Shure Drive, Arlington Heights, IL 60004-1440 (708) 392-5800

The Influence of Depth and Type of Cover Material on Tree Establishment on a Domestic Refuse Landfill Site. 1982. Elsevier Publishing Company.

Thomas, J.W., Ed. 1979. Wildlife habitats in managed forests – the Blue Mountains of Oregon and Washington. Agriculture Handbook No. 553. U.S.D.A. Forest Serv. Washington. 512 pp.

Thornburg, A.A. and S.H. Fuchs. 1978. Plant materials and requirements for growth in dry regions. Chap. 23, pp 411-423. In: Schaller, Frank W. and Sutton, Paul, Eds. Reclamation of drastically disturbed lands. Amer. Soc. Of Agron., Crop Sci Soc. Of Amer., Soil Sci. Soc. Of Amer. Madison, Wisc.

USDA Soil Cons. Svc. 1972. Environmental planting. In: Minimizing Erosion in Urban Areas: Guidelines, Standards, and Specifications. Publ. By USDA Soil Conservation Service, Madison, WI. Pp. 117-143.

U.S. Environment Protection Agency. 1975. Methods of quickly vegetating soils of low productivity, construction activities. EPA-440/9-75-006. U.S. Envt. Protection Agency, Washington, D.C. 467pp.

U.S. Environment Protection Agency. 1980b. Lining of waste impoundment and disposal facilities. Office of Water and Waste Management. Manual SW-870. US Government Printing Office. Washington, DC.

U.S. Environmental Protection Agency (USEPA). 1983. Results of the nationwide Urban Runoff Program. Volume 1-Final Report. PB84-285552. Reproduced by U.S. Department of Commerce.

U.S. Environmental Protection Agency (USEPA). 1990. Biological criteria: national program guidance for surface waters. Office Water Regulations and Standards. (WH-585), Washington, D.C. EPA-440/5-90-004. 57 pages.

Van der Valk, A. (editor). 1989. Northern Prairie Wetlands. Iowa State University Press, Ames, IA. 400 pp.

Vartapetian, B.B., I.N. Anderson, and N. Nuritdinov. 1978. Plant cells under oxygen stress. In: Hook, D.D. and R.M.M. Crawford, eds. Plant Life in Anarobic Environments. Ann Arbor, MI: Ann Arbor Science. 564 pp.

Viessman, W., Jr. and M.J. Hammer. 1985. Water Supply and Pollution Control. Harper and Row, NY. 797 pp.

Wathern. P. 1986. Restoring derelict lands in Great Britain. Pages 248-274 in Committee on the Applications of Ecological Theory to Environmental Problems (eds). Ecological knowledge and environmental problem solving. National Academy Press. Washington, DC.

Wallwork, J.A. 1970. Ecology of Soil Animals. McGraw-Hill Publishing Company, Ltd. London. 283 pp.

Waugh, W.J., and G.N. Richardson. 1997. Ecology, design, and long term performance of waste-site covers: Applications at a uranium mill tailings site. P. D-36 to D-49. In Barrier technologies for environmental management. Natl. Res. Counc., Natl. Academy Press. Washington, D.C.

Weaver, J.E. 1954. North American Prairie. Lincoln, Nebraska: Johnsen Pub. Co. 348 pp.

Weaver, J.E. 1956. Grasslands of the Great Plains. Lincoln, Nebraska: Johnsen Pub. Co. 395 pp.

Weaver, J.E. 1968. Prairie Plants and Their Environment. Univ. of Nebraska. Press Lincoln and Landon. 276 pp.

Weaver, J.E. 1920. Root development in the grassland formation. Carnegie Inst. Wash., Pub. 292.

Whitlow, T.H. and R.W. Harris. 1979. Flood tolerance in plants: a state of the art review. Dept. of Env. Hort., Univ. of Calif., Davis. Tech Rept. E-79-2. For: U.S. Army Corps of Eng., Waterways Exp. Sta., Env. Lab., Vicksburg, Miss.

Wilcox, D.A., S.I. Apfelbaum, and R.D. Heibert. 1985. Cattail Invasion of Sedge Meadows Following Hydrologic Disturbance in the Cowles Bog Wetland Complex, Indiana Dunes National Lakeshore. Wetlands (4):115-128.

Wilson, E.O. (ed.). 1988. Biodiversity. National Academy Press, Washington, D.C. 521 pages.

Wilson, W.H.W. 1984. Landscaping with wildflowers and native plants. Ortho Books. Chevron Chem. Co. San Francisco. 96 pp.

Wing, R.N. and G.W. Gee. 1994. Quest for the perfect cap. Civ. Eng. (NY) 64:38-41.

Wong, M.H., and C.T. Yu. 1989b. Monitoring of Gin Drinker's Bay landfill, Hong Kong II. Gas contents, soil properties, and vegetation performance on the side slope. Environmental Management 13:753-762.

Woods, Richard D., Editor, June 15-17, 1987. Geotechnical Practice for Waste Disposal '87, Proceedings of a Specialty Conference sponsored by the Geotechnical Engineering Division of the American Society of Civil Engineers, University of Michigan Ann Arbor, Michigan, June 15-17, 1987; Geotechnical Special Publication No. 13. Published by the American Society of Civil Engineers, 345 E. 47th St., New York, NY 10017-2398.

Yahner, R. 1980a. Avian winter abundance patterns in farmstead shelterbelts: Weather and temporal effects. 29 pp. Mimeo.

Yahner, R. 1980b. Breeding bird records for Minnesota shelterbelts. Amer. Birds 34(1): 71-73.

Young, B. Additional Recommended Criteria to the Landscape Plan as per Part 360 Regulations, NYC Sanitation Department G. Robinson, Rutgers State University.

TABLE 1: This table summarizes the performance of representative herbaceous and woody) plant species that may be included in the sites planting plans. The criteria for valuing each species by the various attributes are identified in the Vegetation Criterion Key. The experience of ecologists with Applied Ecological Services and a multitude of references were used to classify species (see bibliography).

TABLE 1A. Identification of vegetation criteria used in evaluating compatibility with GCC/GCL.

CLAY CAP
VEGETATION CRITERIA KEY

COMPATIBILITY WITH THE DESIGN INTENT

1. Presence in the Region

H – Found in the presettlement landscape.
M – Was not found in the region at presettlement but has naturalized.
L – Was not found in the region during presettlement.

2. Native

Y – Plant native to the area.
N – Plant is not native to the area

3. Habitat Value for Food

H – Provides excellent food source for many species (i.e. seed, nectar).
M – Provides food source for a few wildlife species.
L – Provides no source of food for wildlife.

4. Habitat Value for Cover

H – Provides excellent cover for nesting, breeding and protection.
M – Provides some cover.
L – No cover.

5. Seasonal Interest

H – Colorful flowers, texture or stature.
M – Compliments dominants
L – Subdominant, not conspicuous

6. Non-Invasive

H – Does not invade.
M – Does invade if certain conditions are met.
L – Invades areas by reseeding or root growth.

7. Soil Types

B – Broad Range of Tolerance
C – Clay Types
L – Loam Types
P – Peat Types
S – Sand Types

ADAPTABILITY TO THE CAPPED SITE ENVIRONMENT

1. Root system type/depth

   B – Bulb
   R – Tap root
   R – Rhizome
   F – Fibrous
   S – Shallow 1-12”
   D – Deep 8-24”

2. Susceptibility to Gases

   H – Plant will not survive exposure to some gas.
   M – Plant may be affected by exposure to some gas.
   L – Plant is tolerant to gas.

3. Reaction to Higher Ground Temperatures

   H – Plant growth and survivability is strongly affected.
   M – Plants may be stressed.
   L – Plants are not affected.

4. Susceptibility to Ground Water Pollution

   H – Plants growth and survivability is strongly affected.
   M – Plants may be stressed.
   L – Plants are not affected.

5. Susceptibility to Surface Settlement

   H – Plant mortality due to root zone shearing.
   M – Plants may be stressed.
   L – Plants are not affected by root zone shearing.

6. Susceptibility to Wind Throw

   H – Plants are very sensitive to high winds.
   M – Plants may be stressed.
   L – Plants are not affected.

7. Adaptability to Soil Compaction

   H – Plants will adapt.
   M – Plants may adapt.
   L – Plants will not adapt.

8. Tolerance of Low Soil Oxygen Conditions

   H – Plants tolerate low oxygen conditions.
   M – Plants may be stressed by low oxygen conditions
   L – Plants will not survive low oxygen conditions.

9. Tolerance of Cover Soil Nutrients and pH.

H – Plants tolerant to variable nutrient and soil pH conditions.
M – Plants tolerate to certain conditions.
L – Plants restricted to a narrow range of conditions.

10. Adaptability to side Slope Conditions

Y – Plants tolerate side slope conditions.
N – Plants will not tolerate side slope conditions.

11. Height at Maturity

“ – inches
‘ – feet

12. Erosion Control

H – Plant provides highly stable soil in the root zone.
M – Plant may provide erosion control.
L – Plant provides no soil stabilizing in root zone.

13. Resistant to Drought

H – Plant is highly adapted to drought conditions.
M – Plant may adapt to certain drought conditions.
L – Plant is not adapted to drought.

MAINTENANCE

1. Rate of Growth

F – Fast
M – Medium
S – Slow

2. Establishment Period

1 – One growing season.
1.5 – One and one half growing Seasons
2 – Two growing Seasons.

3. Longevity

L – Long lived perennial.
M – Short lived perennial.
S – Annual or biannual.

4. Susceptibility to Desiccation

H – Plants are highly susceptible to desiccation.
M – Plants may be susceptible to desiccation.
L – Plants are not susceptible to desiccation.

5. Susceptibility to Rodent/Rabbit Damage

   H – Plants are vulnerable.
   M – Plants may be vulnerable.
   L – Plants are not vulnerable.

6. Susceptibility to disease and Insects

   H – Plants are vulnerable.
   M – Plants may be vulnerable.
   L – Plants are not vulnerable.

7. Compatibility with the Climate

   H – Plants are highly compatible.
   M – Plants may be compatible.
   L – Plants are not compatible.

TABLE 1B
CRITERIA AND SCORING USED IN TABLE 2

	1	2	3
EROSION CONTROL			
Rooting Depth	Deep	Shallow	Surface
Rooting Structure	Course	Fibrous	Densely fibrous
Rooting Habit	Horizontal Condensed	Horizontal Dispensed	Trailing clonal, stoloniferous, rhizomes
Adaptability to Gradient	Intolerant to gradient	May adapt	Rapid establishment
CLIMATE COMPATIBILITY			
Winter Extremes	Intolerant	Moderately tolerant	Tolerant
Summer Extremes	Intolerant	Moderately tolerant	Tolerant
MAINTENANCE			
Drought Tolerance	Intolerant	Moderately tolerant	Tolerant
Tolerance to Compacted Soils	Intolerant	Moderately tolerant	Tolerant
Disease/Insect Resistance	Vulnerable	Moderately resistant	Resistant
Longevity	Short-lived	Moderately-lived	Long-lived
DESIGN, POST-CLOSURE LAND USE			
Native to NE	Non-native	Native-rare	Native-common
Common to NE	Not present	Present	Common-naturalized
Habitat – Food Value	No value	Supports a few species	Supports many species
Habitat – Shelter	No value	Some cover	Excellent for nesting, protection
Seasonal interest	Not conspicuous	Showy flower or fruit display	Showy flower and fruit display
TOLERANCE OF GAS			
Tolerance of Low Soil Oxygen	Will not survive	Possibly stressed	Tolerant
Tolerance of Gases	Will not survive	Possibly stressed	Tolerant
Native to NE	Non-native	Native-rare	Native-common
PROTECTION OF COVER SYSTEM			
Root System Depth	Deep	Shallow	Surface

TABLE 2: An assessment of the suitability/compatibility of native prairie grasses and wildflowers and exemplenry trees and shrubs for planting in clay capped sites including sites with GCC and GCL. Rankings follow the criteria in Table 1A and 1B.

TABLE 2.

PLANT SPECIES	EROSION CONTROL				CLIMATE COMPATI-BILITY		MAINTENANCE				DESIGN, POST-CLOSURE AND USE						TOLERANCE OF GAS		
DECIDUOUS CANOPY TREES	Rooting Depth	Rooting Structure	Rooting Habit	Adaptability to Gradient	Winter Extremes	Summer Extremes	Drought Tolerance	Tolerance to Compacted Soils	Disease/Insect Resistance	Longevity	Native to N.E.	Common to N.E.	Habitat-Food Value	Habitat-Shelter	Seasonal Interest	Conspicuous Flower/Fruit	Tolerance to Low Soil Oxygen	Tolerance to Gases	Native to N.E.
Acer saccharum	3	3	1	1	3	3	3	3	2	3	3	3	3	2	3	1	3	3	3
Fraxinus americana	2	3	1	2	3	2	2	2	2	3	3	3	1	2	3	1	3	2	3
Fraxinus pennsylvanica	2	3	1	1	3	3	3	3	2	3	3	3	1	2	3	1	3	2	3
Quercus bicolor	2	3	1	1	3	3	3	3	3	3	3	3	3	2	3	2	3	2	3
Salix amygdaloides	2	3	3	1	3	3	3	3	2	1	3	1	3	2	1	1	3	2	3
Salix nigra	2	3	3	1	3	3	3	3	2	2	3	3	3	2	1	1	3	3	3
Tilia americana	1	1	2	3	3	1	1	1	2	3	3	3	1	2	3	1	2	2	3

PLANT SPECIES	**EROSION CONTROL**				**CLIMATE COMPATI-BILITY**		**MAINTENANCE**				**DESIGN, POST-CLOSURE AND USE**						**TOLERANCE OF GAS**		
DECIDUOUS UNDERSTORY TREES	Rooting Depth	Rooting Structure	Rooting Habit	Adaptability to Gradient	Winter Extremes	Summer Extremes	Drought Tolerance	Tolerance to Compacted Soils	Disease/Insect Resistance	Longevity	Native to N.E.	Common to N.E.	Habitat-Food Value	Habitat-Shelter	Seasonal Interest	Conspicuous Flower/Fruit	Tolerance to Low Soil Oxygen	Tolerance to Gases	Native to N.E.
Amelanchier canadensis	2	3	3	2	3	1	1	1	3	2	3	2	3	3	3	3	2	2	3
Cercis canadensis	2	3	3	3	2	3	3	2	3	2	2	3	1	2	3	3	2	2	2
Cornus mas	2	2	3	1	2	2	3	2	3	2	1	1	3	3	1	2	2	3	1
Crataegus crus-galli	1	2	1	3	3	3	3	2	2	2	1	3	2	3	3	3	2	2	1
Prunus virginiana	2	3	3	2	3	3	3	1	2	2	3	1	3	2	3	2	2	3	3
Ptelea trifoliata	2	2	3	3	3	3	3	1	3	2	3	1	2	2	2	1	1	3	3
Rhus copallina latifolia	2	1	3	3	2	3	3	1	3	1	1	1	3	2	3	3	2	3	1
Rhus glabra	2	3	3	3	3	3	3	1	3	1	3	3	3	2	3	3	2	3	3
Rhus typhina	2	3	3	3	3	3	3	1	3	1	3	3	3	2	3	3	2	3	3
Salix discolor	2	3	3	1	3	3	3	3	1	1	3	2	3	2	1	3	3	3	3
Viburnum lentago	2	3	3	3	3	3	3	1	3	1	3	2	3	2	3	2	2	3	1
Viburnum prunifolium	2	3	2	3	3	3	3	1	3	2	3	2	3	3	3	3	1	2	3
Zanthoxylum americanum	2	3	3	3	3	3	3	1	3	3	3	3	3	2	2	1	2	3	3

PLANT SPECIES	**EROSION CONTROL**				**CLIMATE COMPATI-BILITY**		**MAINTENANCE**				**DESIGN, POST-CLOSURE AND USE**						**TOLERANCE OF GAS**		
DECIDUOUS SHRUBS	Rooting Depth	Rooting Structure	Rooting Habit	Adaptability to Gradient	Winter Extremes	Summer Extremes	Drought Tolerance	Tolerance to Compacted Soils	Disease/Insect Resistance	Longevity	Native to N.E.	Common to N.E.	Habitat-Food Value	Habitat-Shelter	Seasonal Interest	Conspicuous Flower/Fruit	Tolerance to Low Soil Oxygen	Tolerance to Gases	Native to N.E.
Aronia melanocarpa	3	3	3	3	3	3	3	3	3	1	3	2	2	2	3	2	3	3	3
Cornus amomum	3	3	3	1	1	3	3	3	2	1	3	2	3	2	2	2	3	2	3
Cornus racemosa	3	3	3	3	1	3	3	2	3	3	3	3	3	2	2	3	2	2	3
Cornus stolonifera	3	3	3	1	3	3	3	3	2	1	3	3	3	2	3	3	3	3	3
Corylus americana	2	3	3	3	3	2	2	2	3	3	3	2	2	2	2	1	1	3	3
Hamamelis vernalis	2	3	3	1	2	2	2	3	3	2	1	1	1	2	3	2	3	1	1
Rhus aromatica	3	3	3	3	3	3	3	1	2	2	1	2	3	2	3	2	1	3	1
Salix humilis	3	3	2	3	2	3	3	3	3	1	3	3	3	2	1	1	3	3	3
Salix lucida	3	3	2	1	2	3	3	3	1	1	3	2	3	2	1	1	3	3	3
Sambucus canadensis	3	3	3	2	3	3	3	3	2	2	3	3	3	2	1	3	3	3	3
Viburnum acerifolium	3	3	3	3	3	2	2	2	2	3	3	1	3	2	3	2	1	3	3
Viburnum dentatum	3	3	3	1	3	3	3	2	3	3	1	2	3	2	2	2	3	3	1
Viburnum trilobum	3	3	2	3	3	3	3	3	3	3	3	3	3	2	2	3	3	2	3
Viburnum lantana	3	3	3	3	3	3	3	2	3	3	1	1	3	2	1	3	1	3	1

PLANT SPECIES	EROSION CONTROL				CLIMATE COMPATI-BILITY		MAINTENANCE				DESIGN, POST-CLOSURE AND USE						TOLERANCE OF GAS		
PRAIRIE GRASSES AND FORBS	Rooting Depth	Rooting Structure	Rooting Habit	Adaptability to Gradient	Winter Extremes	Summer Extremes	Drought Tolerance	Tolerance to Compacted Soils	Disease/Insect Resistance	Longevity	Native to N.E.	Common to N.E.	Habitat-Food Value	Habitat-Shelter	Seasonal Interest	Conspicuous Flower/Fruit	Tolerance to Low Soil Oxygen	Tolerance to Gases	Native to N.E.
**Andropogon gerardii*	2	3	3	3	3	3	3	3	3	3	3	3	1	3	3	2	3	3	3
**Andropogon scoparius*	2	3	3	3	3	3	3	3	3	3	3	3	1	3	3	2	1	3	3
Anemone cylindrica	1	3	3	3	3	3	3	3	3	3	3	3	2	1	3	2	3	3	3
Argrostis alba	3	3	2	3	3	3	3	3	3	3	1	2	1	3	3		3	3	1
Aster azureus	3	2	2	3	3	3	3	3	3	3	3	3	1	1	3	2	2	2	3
Aster ericoides	3	3	3	3	3	3	3	3	3	3	3	2	2	2	3	2	3	3	3
Aster laevis	3	2	2	3	3	3	3	3	2	3	3	3	1	1	3	2	2	2	3
Aster novae-angliae	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	2	3	3	3
**Bouteloua curtipendula*	2	3	3	3	3	3	3	3	3	3	3	3	1	3	3	2	3	3	3
**Bouteloua gracilis*	2	3	3	3	3	3	3	3	3	3	3	3	1	3	3	2	3	3	3
**Bouteloua hirsuta*	2	3	3	3	3	3	3	3	3	3	3	3	1	3	3	2	3	3	3
**Buchloe dactyloides*	2	3	3	3	3	3	3	3	3	3	3	3	1	3	3	2	3	3	3
Coreopsis palmata	3	3	3	3	3	3	3	2	3	3	3	3	3	1	3	2	2	3	3
Desmodium canadense	1	1	1	3	3	3	3	3	3	3	2	2	2	1	2	3	3	3	3
Echinacea pallida	1	2	1	3	3	3	3	3	3	3	2	2	2	1	2	3	3	3	3
Elymus canadensis	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3
Elymus villosus	2	3	3	3	3	3	3	2	3	3	3	3	3	3	3	1	3	1	3
Elymus virginicus	2	3	3	3	3	3	3	2	3	3	3	3	3	3	3	1	3	1	3

*** THESE SPECIES ARE INCLUDED AS EXAMPLES IN THE “DOWNTOWN OMAHA RIVERFRONT DESIGN DEVELOPMENT SUMMARY REPORT (UNEDITED).**

PLANT SPECIES	EROSION CONTROL				CLIMATE COMPATIBILITY		MAINTENANCE				DESIGN, POST-CLOSURE AND USE						TOLERANCE TO GAS		
PRAIRIE GRASSES AND FORBS	Rooting Depth	Rooting Structure	Rooting Habit	Adaptability to Gradient	Winter Extremes	Summer Extremes	Drought Tolerance	Tolerance to Compacted Soils	Disease/Insect Resistance	Longevity	Native to N.E.	Common to N.E.	Habitat-Food Value	Habitat-Shelter	Seasonal Interest	Conspicuous Flower/Fruit	Tolerance to Low Soil Oxygen	Tolerance to Gases	Native to N.E.
Euphorbia corollata	3	3	3	3	3	3	3	3	3	3	3	3	2	1	3	2	3	3	3
Festuca rubra	3	3	2	3	3	3	3	2	3	3	1	3	1	2	3	1	3	3	1
Helianthus divaricatus	3	3	3	3	3	3	3	2	3	3	3	3	3	2	3	2	2	2	3
Helianthus laetiflorus	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	2	3	3	3
Lespedeza capitata	1	2	3	3	3	3	3	3	3	3	3	2	2	2	2	3	3	3	3
Monarda fistulosa	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	2	3	3	3
Panicum virgatum	2	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3	3	3
Petalostemum purpureum	1	2	2	3	3	3	2	2	3	3	3	3	3	1	3	3	2	3	3
Phleum pratense	3	3	1	3	3	3	3	3	3	3	2	3	1	3	2	2	3	3	1
Potentilla arguta	3	3	1	3	3	3	3	3	3	3	3	3	3	1	3	2	1	2	3
Ratibida pinnata	3	3	3	3	3	3	3	3	3	2	3	3	3	1	3	2	1	3	3
Rudbeckia hirta	3	3	3	3	3	3	3	3	3	2	3	3	3	1	3	2	1	3	3
Rudbeckia triloba	2	3	3	3	3	3	3	1	3	3	3	3	2	1	3	2	2	2	3
Silphium terebinthinaceum	2	2	1	3	3	3	3	3	2	3	3	3	3	1	3	3	3	1	3
Solidago canadensis	3	3	3	3	3	3	3	3	3	2	3	2	2	2	3	2	3	3	3
Solidago nemoralis	3	3	2	3	3	3	3	3	2	3	3	3	2	1	3	2	1	3	3
Solidago rigida	3	2	1	3	3	3	3	3	3	3	3	3	3	1	3	2	1	3	3
Solidago speciosa	3	3	2	3	3	3	3	3	3	3	3	3	2	1	3	2	1	2	3
Sorghastrum nutans	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	1	3