Unique Landfill Restoration Designs Increase Opportunities to Create Urban Open Space

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The majority of humans now live in cities where access to usable open space is often limited, causing a reexamination of current practices and values related to reuse of available urban lands. Closed landfills offer an unprecedented opportunity to convert large underutilized land into usable urban open space, as well as habitat for multiple species. However, existing landfill regulations and closure practices do not allow optimal ecological restoration designs for these underutilized properties to be realized, because current regulations focus on methods that protect required caps and prevent water infiltration. Through the exploration of two design case studies, the authors illustrate the opportunities to increase habitat diversity on closed landfills and to more closely approximate a natural topographic/vegetation interaction. Although initially a more costly restoration, unique restoration design elements enhance both long-term environmental and socio-economic values associated with the reuse of closed urban landfills, which are currently underutilized.

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Sometime in 2008 an unprecedented global demographic transition occurred—the majority of humans now live in cities (Flavin, 2007). Over the next century, urban environments are projected to accommodate an additional 3 billon people (United Nations, 1987). This worldwide process of urbanization demands that we consider the nexus between industrial, residential, and urban open space. In this paper we exam the potential to enhance the social and environmental values of a closed urban landfill through two landscape design case studies.

The United States generates ~250,000 million tons of municipal solid waste (MSW) annually, the majority of which is consigned to a landfill, of which there are ~1,908 in operation (USEPA, 2012). Prior to 1970, MSW disposal was unregulated, and waste was often discarded in unlined pits. Federal regulations enacted in the 1980s and 1990s required specific actions to close a landfill, and landfills accepting waste after 1993 now follow the US Environmental Protection Agency (USEPA) regulations. These federal rules require surface covers, liners, and leachate collection devices/systems (USEPA, 1991, Christenson and Cozzarelli, 2003). The purpose of the regulations is to minimize water infiltration into the waste and to prevent erosion of the surface cover, which must consist of a hydraulic barrier layer at least 45.7 cm in thickness overlain by an erosion control layer at least 15.2 cm thick; specific low hydraulic conductivity parameters are required for the barrier layer, and post-closure regulations prohibit disturbance of these required components (USEPA, 1991). However, USEPA does allow the Director of an Approved State to establish alternative infiltration layers for final cover, if they are protective of human health and the environment (USEPA, 1997). There are studies suggesting that alternative covers, especially in arid and semi-arid environments, can be as effective as conventional final covers in controlling water infiltration (Albright et al., 2004). Evapotranspiration covers store water during high precipitation events and releases this stored water through evapotranspiration during periods of low precipitation.

The United States may have as many as 10,000 "retired" landfills (Sulfita et al., 1992), which are no longer receiving

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waste; Sampson (2009) estimates that over 6,000 US landfills have been closed since 1988. Transformation of what was formerly the world's largest landfill (NYC Parks, 2016) into the 2,200 acre Freshkills Park is an example of the untapped resource potential of US landfills. Former landfill properties are contaminated by their contents and are unstable due to the decomposition of organic material, followed by gas release and subsequent landfill subsidence. For these reasons, appropriate adaptive reuse options do not include commercial or residential development. However, as illustrated by Freshkills Park, landfill sites represent hundreds of thousands of acres that could contribute public open space amenities and increase urban habitat values if they are redesigned using approaches that support ecological and recreational values, while ensuring protection of human health and the environment.

USEPA (1991) closure and post-closure guidelines focus on protecting the integrity of the landfill capping system. Locally adapted perennial plants and grasses are recommended as the vegetative cover for capped landfills, and USEPA suggests that deep rooted shrubs and trees are "inappropriate" choices for planting on a closed landfill due to the potential for penetrating the infiltration layer (USEPA, 1991), although alternative covers have incorporated woody stemmed vegetation (Albright et al., 2004). Arguments against the use of woody species include potential disruption of the cap materials via root penetration or uprooting by windfall, which may allow water to penetrate into the waste, resulting in increased volumes of toxic leachate and the escape of landfill gases. Given the low permeability of the required barrier layer material, as well as USEPA's encouragement to limit plantings to perennials and grasses, the majority of design options for landfill reuse typically do not include natural vegetation patterns, biodiversity of plant species, or woody species.

However, if the unrealized potential of closed landfill resources is to be achieved, new ecologically functional and esthetically interesting design options and approaches are needed. The ecosystem service values of the lawn or field environment typically employed in landfill closures can be enhanced with the addition of woody plant species. Trees and shrubs increase evapotranspiration rates, enhance rainwater intercept values, and add a vertical dimension to the plant assemblage structure, which supports increased wildlife diversity. Trees provide shade, scale, and seasonal interest; they are the elements which transform a grass covered landfill into a public park amenity.

Although actual data describing effects attributable to planted woody stemmed species and their roots on closed landfills are limited, a few scientific studies have been conducted. However, the results of these studies are inconclusive. Dobson and Moffat (1995) summarized the issues related to planting trees on landfills. Their review of the physical and chemical requirements of roots, as well as root morphology, concluded that it should be possible to plant trees on landfills without disrupting the cap. Subsequent field studies (Robinson and Handel, 1995; Handel et al., 1997; Holl and McStay, 2014) have confirmed the assessment that tree roots would not penetrate the cap and that roots would expand in shallow lateral directions. Hutchings et al. (2001, 2006) found the depth of the fill material should be at least 1.3 m in thickness to prevent root incursions into the waste material. Moffat et al. (2008) found no evidence of root interaction with the landfill containment or gas system 10 years after planting. Conversely, Mooney et al. (2007) observed root penetration through the cap and attributed this to zones of cap weakness that resulted from inconsistencies in particle and pore size and low bulk density. Even if it is possible to plant woody species without penetrating the cap, there are studies that suggest survival of trees planted in landfill capping material may be precarious. Rawlinson et al. (2004) found mortality of tree species was quite variable, ranging from 26% to 65% depending on plot location and tree species. Oak (*Quercus*) seedlings planted on a closed landfill were found to have low densities of ectomycorrhizal infection (Parsons et al., 1998), suggesting an impaired ability to obtain nutrients.

In short, the current regulatory environment, as well as environmental factors related to landfill cover materials, make it difficult to obtain the required permits or to ensure suitable growth conditions for woody species when designing landfill reuse strategies. In an effort to include trees in landfill redesigns, we present two case studies that explored unique design approaches to overcome these impediments.

Methods

Case Study Site Descriptions

The former Somerville and Voorhees landfills (Figure 1) are situated in central and southern New Jersey (NJ) in the coastal plain (for in depth site descriptions see www.cues.rutgers.edu).

Voorhees Environmental Park (VEP)
The 46-acre site, located in the Township of Voorhees, NJ, was mined for sand and gravel from 1959 to 1966, and

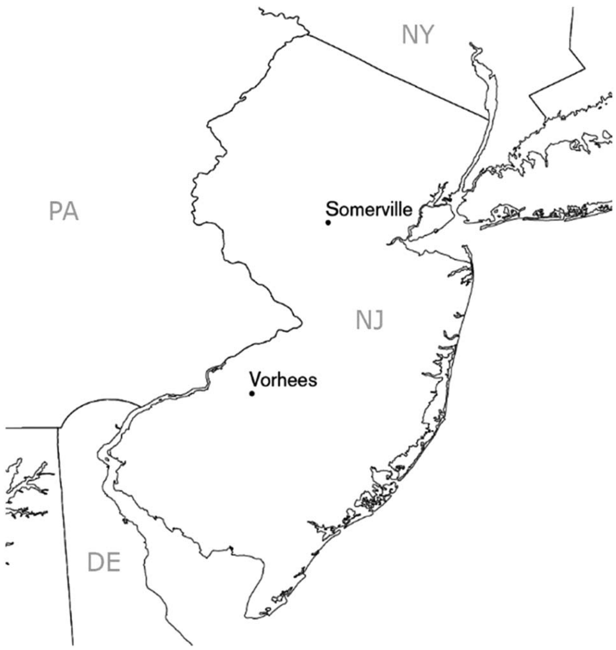

Figure 1. Map of New Jersey with locations of the Townships of Somerville and Voorhees where the landfill case study sites are located.

excavation activities created a deep pit. The pit on the 37-acre Voorhees Township portion of the site was used for MSW from 1966 until capacity was reached in 1972. In 1978, prior to passage of the previously described USEPA regulations, the landfill was closed and capped with 61 cm of soil; no liner or leachate collection system was installed as part of the closure activities. A subsequent 1990s site survey determined that the landfill contained chemicals hazardous to human health. The landfill and the Township of Voorhees are underlain by the 7,770 km^2 Kirkwood-Cohansey aquifer, a drinking water source for southern NJ. Fortunately, the contamination had not leached into the groundwater supply.

The Township of Voorhees and the General Electric Corporation were identified as co-responsible parties, and a remediation plan was developed jointly, which included oxygen injection to support *in situ* bioremediation of organic contaminants. The final site closure plan was approved by New Jersey Department of Environmental Protection (NJDEP) in 2014, allowing the Township of Voorhees to commence redevelopment of the former landfill into a public passive park, although the oxygen sparging system is still in active use around the site perimeter. The original soil cap closure was "grandfathered" and so no leachate collection system or any type of liner is present. Therefore, the need for enough water infiltration to support natural bioremediation processes must be balanced with the need to preclude too much water infiltration that could increase leachate production. Further, the 61-cm earthen cap does not provide enough root depth to sustain tree plantings. To secure funds necessary for ongoing park operation and maintenance, Voorhees Township decided to dedicate a portion of the site to a solar panel array that would provide an ongoing revenue source for park operation and maintenance. This created an interesting design challenge—juxtaposition of the public park with a light industrial power generating installation.

Somerville Green Seam Restoration

The former Somerville municipal landfill, located adjacent to a NJ Transit train station, operated between 1954 and 1984. In 1998 the site was designated an "area in need of redevelopment." The Redevelopment Plan for the Borough of Somerville Station Area and Adjacent Landfill was completed in 2007. Because the borough is home to the Somerset County seat and much of its land does not generate tax revenues to support municipal services, the borough's design priority was maximization of tax rateables.

The site originally contained riparian forested freshwater wetlands, and pockets of this habitat type remain; portions of the redevelopment area lie within the 100 Year Flood Plain. Redevelopment and the addition of multiple impervious surfaces require compliance with NJ stormwater regulations and the management of stormwater that will be generated in an area already prone to flooding. The open space portion of the Redevelopment Plan was identified as the "Green Seam"—a corridor of wetland and surface waters that will connect the existing commercial downtown businesses with high density commercial mixed land uses, moderate density town houses, low rise apartments, and offices.

Designing the Green Seam presented significant challenges and opportunities. The landscape has had many topographic, soil, and vegetation alterations due to environmental impacts related to both the landfill operation and the train station; the site's groundwater is contaminated. The closure of this landfill is subject to USEPA rules requiring protective cap layers, geosyntec liners, and a collection system for the contaminated groundwater, which will be recovered, treated, and discharged into the wetland system in the northern portion of the site. The estimated daily addition of approximately 70,000 gallons of treated water will increase flow rates into the stream which will cross the capped landfill. The proposed redevelopment of the landfill represents an opportunity to explore not only the potential

Figure 2. Voorhees Environmental Park Conceptual Restoration Plan.

Figure 3. Somerville Green Seam and Transit Station Redevelopment Conceptual Restoration Plan.

for commercial and residential redevelopment of a former industrial site, but also the restoration and enhancement of the site's remaining wetlands.

The proposed restoration plans for both sites (Figures 2, 3) reintroduced woody species and tree canopies to increase species assemblage, create a more natural forested riparian topography (Somerville), and create a visually interesting landscape (Voorhees). One option considered to support the introduction of woody stemmed vegetation was installation of final soil caps with depths greater than the required 61 cm. However, this approach would involve significant additional costs that these publically funded projects did not want to incur. Therefore, the design challenge was to find alternative approaches that would allow placement of trees on the former landfills without jeopardizing the cap or liner systems, while providing the necessary depth of soil matrix for successful survival and long-term growth of woody stemmed species.

Design Interventions Supportive of Woody Species

Voorhees Environmental Park Promenade

A significant VEP design element is the tree-lined Promenade, which runs the length of the park, and provides connections to the pond water feature, main entrance, parking lot, and solar field. The tree species selection (Figure 4) took into consideration shade tolerance, height, space, and site environmental conditions. Other factors such as fall color and flowering/fruiting elements added character, while offering habitat and food for local fauna.

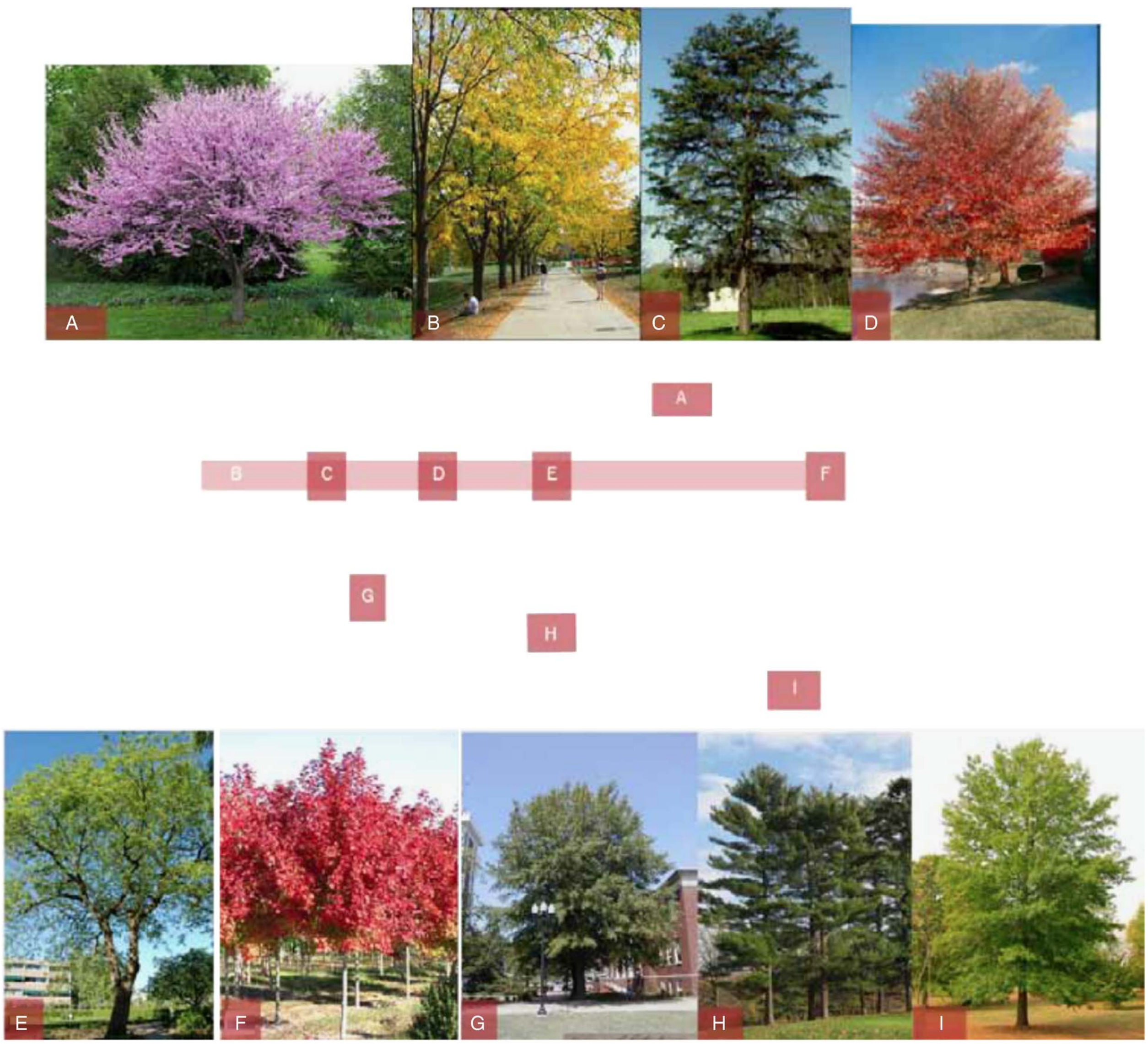

Figure 4. Tree assortment selected for promenade and bosquet plantings: **A:** Eastern Redbud, *Cercis Canadensis*; **B:** Thornless Honeylocust, *Gleditsia tricanthos var. inermis*; **C:** Virginia Pine, *Pinus virginiana*; **D:** Blackgum, *Nyssa sylvatica*; **E:** Shagbark Hickory, *Carya ovate*; **F:** Red Maple, *Acer rubrum*; **G:** Willow Oak, *Quercus phellos*; **H:** White Pine, *Pinus strobus*; **I:** Pin Oak, *Quercus palustris.*

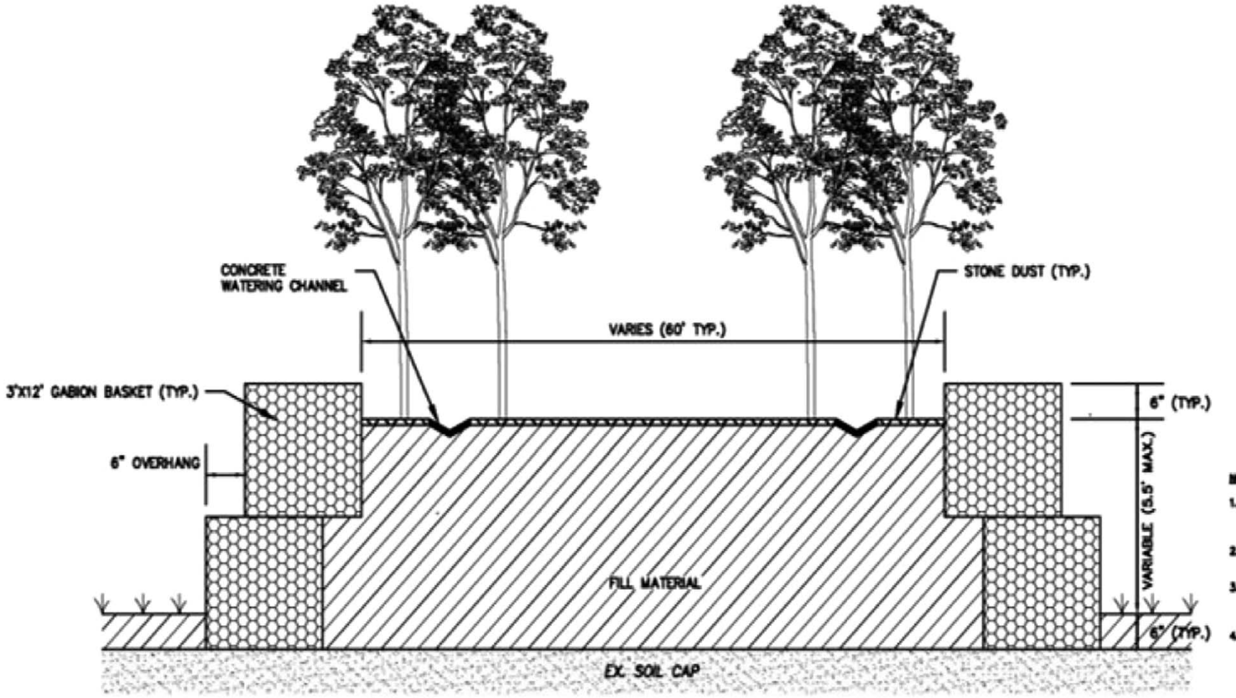

Figure 5. A gabion retaining wall retains clean topsoil fill placed on top of the 61 cm landfill cap, supporting shade trees along promenade. Drainage channels allow irritation water to flow downhill toward the surface pond. Drawing courtesy of CME engineering.

Figure 6. Trees provide a shaded area for walking, biking, or sitting on the promenade to enjoy the viewshed created by this elevated structural element.

The Promenade design includes ~180 cm of soil/nutrient material placed on top of the existing 61-cm cap (Figure 5) after a period of mechanical compression of the underlying landfill substrate. This planting media will be held in place by two gabion walls and irrigated by a gravity-fed water system. The use of gabions allows for stable retaining walls that do not penetrate the cap and are more flexible than concrete to adjust to potential further subsidence of the landfill. Along the Promenade the dominant tree is the thornless honey locust (*Gleditsia tricanthos* var. inermis). Known for its dappled shade pattern and fall color, the honey locust is a beautiful tree when planted en masse (Figure 6). The bosquets of blackgum (*Nyssa sylvatica*) and red maple (*Acer rubrum*) on the Promenade are known for their brilliant red and orange fall color. Shagbark hickory (*Carya ovata*) has shaggy bark, offering winter interest to compliment the evergreen bosquet of Virginia pine (*Pinus virginiana*).

Water for irrigation will be collected from runoff generated by solar panels located on the highest point of the site and stored in a below ground cistern. The trees will be irrigated with the stormwater that is now flowing off site and eroding a drainage ditch on the site perimeter. The re-use of concrete as gabion material will reduce construction cost and the overall carbon footprint of the project. This innovative gabion system will provide a high point to view the entire park vista.

Somerville Green Seam Restoration

The design planning process stressed the integration of ecological resource significance with community socio-ecconomic redevelopment needs. Due to anthropogenic forcing (i.e., filling and addition of hardscape) and the separation of ground water and surface water, the existing

Figure 7. Rendering of the transition area between the proposed capped Somerville Landfill and the existing wetland. The proposed enhanced wetlands increase stormwater retention while serving as points of public access.

hydrologic system has become increasingly "flashy," exhibiting a significant loss of water retention within the watershed and particularly on the landfill site itself. Therefore several design interventions are proposed to enhance onsite water retention. Wetland improvements (Figure 7) include the deepening of wetland areas to enhance water storage and to create standing water habitat. These enhanced wetlands also include forbay areas to capture sediment, thereby facilitating maintenance.

The team's environmental engineer analyzed the hydrologic system using a USDA National Resources Conservation Service (NRCS) methodology and then developed hydraulic models of the creek's existing and proposed conditions using USEPA's Storm Water Management Model (SWMM) software. The nodes of the creek's channel network were based on aerial reference imagery. Stream transects were based on field survey data, and proposed engineered conditions were used to approximate the shape of each channel section. The model input included precipitation time series for multiple storm events (2-yr, 10-yr, 25-yr, 50-yr, and 100-yr design storms) and topographically delineated subcatchments. A comparison of the simulated water heights for proposed conditions under different storm scenarios provided information for the team's landscape architects to design "creek terraces" and select hydrologically compatible vegetation (Table 1). The terraces were placed on top of the soil/geosyntec liner capping system; soil depths inside the terrace structures increase as the terraces are placed farther away from the creek bank edges (Figure 8).

Vegetation was selected to mimic a natural riparian corridor assemblage, with grasses in the lower flood plain and herbaceous cover, woody shrubs, and tree species at the higher elevations that flood only during larger or extreme events. The terraces provide overlook connections to the site's planned trail system. The vegetation mimics a natural riparian wetland species assemblage and the terraces house the depth of soil and nutrient materials needed to support woody species and provide increased retention and slow release of storm- and flood-waters.

Discussion

Increasing population density in the urban environment requires an integrated engineering, landscape planning, and

Table 1. Somerville green seam plant list.

Scientific Name	Common Name	Design Location
Acer rubrum	Red maple	Second terrace, Upper terraces
Amelanchier canadensis	Canadian serviceberry	Upper terraces
Andropogon gerardii	Big bluestem	Mid terraces
Andropogon virginicus	Broomsedge bluestem	Upper terraces
Asclepias incarnata	Swamp milkweed	Second terrace
Betula nigra	River birch	Second terrace, Mid terraces
Carex crinita	Fringed sedge	Herbaceous wetland
Carex lupulina	Hop sedge	Herbaceous wetland
Carex lurida	Shallow sedge	Herbaceous wetland
Carex stipata	Awlfruit sedge	Herbaceous wetland
Carex stricta	Upright sedge	Herbaceous wetland
Carex vulpinoidea	Fox sedge	Herbaceous wetland
Carpinus caroliniana	American hornbeam	Upper terraces
Cephalanthus occidentalis	Common buttonbush	First terrace
Cornus amomum	Silky dogwood	Second terrace
Eleocharis palustris	Creeping spikerush	First terrace
Elymus virginicus	Virginia wildrye	Second terrace
Eupatorium perfoliatum	Common boneset	Second terrace
Eupatorium purpureum	Sweetscented joe pye weed	Mid terraces
Fraxinus pennsylvanica	Green ash	Upper terraces
Hibiscus moscheutos	Crimsoneyed rosemallow	Herbaceous wetland
Iris versicolor	Harlequin blueflag	Herbaceous wetland, First terrace
Juncus effusus	Common rush	Herbaceous wetland, First terrace, Second terrace
Leersia oryzoides	Rice cutgrass	Herbaceous wetland
Lobelia cardinalis	Cardinalflower	Herbaceous wetland, First terrace
Lobelia siphilitica	Great blue lobelia	Herbaceous wetland, First terrace
Ludwigia alternifolia	Seedbox	Herbaceous wetland
Mimulus ringens	Allegheny monkeyflower	First terrace, Second terrace
Morella pensylvanica	Northern bayberry	Mid terraces
Photinia pyrifolia	Red chokeberry	Second terrace
Populus tremuloides	Quaking aspen	Upper terraces
Rhus aromatica	Fragrant sumac	Mid terraces, Upper terraces
Rosa carolina	Carolina rose	Mid terraces
Rosa virginiana	Virginia rose	Second terrace
Rudbeckia laciniata	Cutleaf coneflower	Second terrace
Rudbeckia triloba	Browneyed Susan	Mid terraces
Sagittaria latifolia	Broadleaf arrowhead	Herbaceous wetland
Salix nigra	Black willow	Mid terraces
Sassafras albidum	Sassafras	Mid terraces
Scirpus cyperinus	Woolgrass	Herbaceous wetland
Schizachyrium scoparium	Little bluestem	Mid terraces
Sparganium americanum	American bur-reed	Herbaceous wetland

Table 1. (*Continued*)

Scientific Name	Common Name	Design Location
Sparganium eurycarpum	Broadfruit bur-reed	Herbaceous wetland
Symphyotrichum novae-angliae	New England aster	Herbaceous wetland, First terrace
Symphyotrichum novi-belgii	New York aster	Herbaceous wetland, First terrace
Typha latifolia	Broadleaf cattail	Herbaceous wetland
Verbena hastata	Swamp verbena	First terrace
Viburnum dentatum	Southern arrowwood	Second terrace
Viburnum prunifolium	Blackhaw	Mid terraces
Zizia aptera	Meadow zizia	Mid terraces
Zizia aurea	Golden zizia	Second terrace

Figure 8. Typical cross-section indicating elevations needed to capture various storm events, creating both facultative and obligate hydric planting zones. In addition, the approximate depth of fill required to develop shrub and forest guild assemblages is indicated.

design approach that maximizes socio-economic and ecological benefits. Landscape architecture does not just provide decorative open spaces, but can be a driving force in urban and suburban environmental planning and development, supported by an understanding of the role environmental sciences and ecology play in fostering an understanding of nature as a dynamic system. Further, environmental and ecologic sciences have, over the past two decades, shifted attention from analyzing negative human impacts on natural systems toward investigations of the interaction between humans and their environment, as expressed in the concept of ecosystem services (Gallagher et al., 2011). Improving the quality of human life and natural systems within the urban context are now considered parallel objectives. This trend is forging a new path which builds upon landscape and ecological urbanism.

The approaches we have taken in these case studies illustrate the possibility of increasing species biodiversity by more closely mimicking natural assemblages when rehabilitating former landfills. The functional attributes of tree assemblages should be a primary restoration consideration. Rainwater intercept and translocation rates can be increased, decreasing the volume of stormwater, which needs to be managed. The development of wood biomass increases carbon sequestration rates, while providing increased niche depth resulting in enhanced biodiversity. However, to achieve these desirable outcomes, legal and regulatory changes are needed that support ecological values, rather than merely focusing on the containment of leachate or simply capping the contamination. Maximizing urban land uses will only occur when the regulatory approach changes the perception of these properties from one of a 'closed landfill' into one of a 'public open space amenity.'

We acknowledge that a cultural paradigm shift related to adaptive reuse of places now characterized as waste lands or dangerous (Hoefer and Vicenzotti, 2013) to a beneficial resource could potentially result in an increase in landfill restoration/closure costs. However, as benefits and future values (socio-economic and ecologic) are realized, we argue that the higher quality open space would result in increased ecosystem services, as well as increased adjacent property values, providing benefits for the community as a whole. Hence the iterative or indirect economic, social, and ecological benefits could result in an acceptable cost benefit ratio.

Conclusion

Ongoing urbanization results in expansion of settlement areas, intensified heat island effects, and significantly reduced ecosystem values of developed land. Higher population density leads to increased demand for usable urban open spaces for passive and active recreation. Because closed landfills are not suitable for building, and will thus remain open spaces even under high development pressure, the reexamination of current practices of landfill reuse is highly recommended. The case studies presented here offer examples of unique design approaches for closed landfills.

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