Landfill redevelopment: Beneficial use and aftercare

Robert B. Wallace
URS Corporation, Seattle, Washington

Abstract: The practices associated with the environmental drive for controlled landfills in the 1970's, as well as the legacy of the uncontrolled waste dumps of the era before the new awareness, have left a large number of sites deemed unsuitable for future land use. Regulations developed to protect human health and the environment have required owners to manage and monitor these sites for decades. This has always been interpreted as controlled abandonment of land. However, this land need not be fenced off forever. Foresight, planning, and state-of-practice engineering can be used to create beneficial land use of these sites.

Introduction

Developable land is at a premium. This is of particular importance to cities and counties, as growth challenges already stressed resources to provide community services to a demanding and increasing population. An opportunity therefore exists to convert marginally acceptable lands to beneficial land use. This includes municipal solid waste landfills that can be developed for a wide range of future land uses.

Environmental laws governing the site selection, design, construction, operation, closure, and monitoring of landfills has been standardized in the U.S., based on the USEPA Subtitle D regulation, which has been adopted into every State's law. Included in these regulations is a requirement that a post-closure care and maintenance period of at least 30 years be financed by the owner/operator of the facility. This aftercare period includes groundwater monitoring and maintenance of controls on leachate and landfill gas emissions from the site.

Development has consumed almost all prime land, and has spread to the marginal areas. One consequence of this is that contaminated properties have grown in relative value, necessitating consideration of future land use alternatives previously ignored. Practices employed at many such sites have revealed that circumstances previously conceded as insurmountable for re-use of contaminated sites, merely represent constraints that can be overcome during planning, design, and construction.

Growth of urban centers

Urban sprawl is a phenomenon of the post World War II era. This has been fueled by a number of factors. Immigration, which in overwhelming numbers heads to urban areas, has grown at a rate eclipsing turn-of-the-century numbers. In addition, the growth of technology has led to the "de-ruralization" of North America - young people, in particular, are leaving the farms and small towns, and heading for the big city.

The results are clear in North America. From 1975 to the present, virtually every large city in North America has grown even larger, and at a proportion far exceeding the general population growth factor.

The City of Seattle, as with many communities completely surrounded by other towns and cities, has run out of options as far as unincorporated land available for growth. With very minor exceptions, new development must be preceded by demolition of previous development.

European cities have rebuilt above old development for centuries. In North America, with our vast open areas, it never occurred to us that we would run out of land. However, the migration of the population to the cities has brought this phenomenon forward almost before we saw it coming. One consequence has been a revaluation of derelict and marginally developable land.

With the escalation of property values, another dilemma arises. Population growth has required the growth of the public infrastructure and services. Cities, counties, and other public sectors not only must provide more police and fire stations, more mass transit, more public works services, more roads, more utilities - but they must also develop those facilities on prohibitively expensive land.

In many cases, closed landfills and contaminated sites are publicly owned. Utilization of these lands can be a critical component of budget management. As the alternatives for future land use of landfills and similar sites increase, it is possible to turn a liability into an asset.

Development considerations

The majority of landfills being considered for redevelopment today are either previously closed, or pending closure. As a result, most candidate developments are retrofit, accepting the existing conditions as the starting point. In future, however, it will be desirable to address final land use considerations at the earliest stages of site development. Hence, the considerations of siting, design, permitting, construction, operations, and closure will be conducted with the planning for future beneficial use as a driving criterion. The post-closure care and maintenance period for the landfill will have a completely redefined meaning. This need will impact every other consideration.

The following considerations will impact the feasibility of every landfill redevelopment program.

Site selection

Historic site selection has focused on a number of parameters that are independent of any site purpose other than that of waste disposal. The influence of the affected public has been exerted to such a degree that siting of a new landfill remains one of the most difficult tasks in environmental regulation. The result of the "not in my backyard", or NIMBY syndrome, is that new landfills are getting developed farther and farther from population centers. The concept of long haul by rail has allowed optimization of many site selection criteria, while satisfying the public's needs.

The addition of future land use to the site selection process will impact the long-term plans for the site. It will not be a consideration for most new landfills, however. As new landfills are being sited farther and farther from the beaten path, due to the availability of longhaul options, there will be less demand for that land, upon closure, due to the remote siting.

Landfill closure design

Design criteria for landfill closures were established to prevent the emission of landfill gas and the significant infiltration of water into the waste after closure. The cross section of the barrier system includes provisions for adequate drainage of stormwater. Modifications to closure sections to allow construction of new land use facilities must preserve the features of the closure system.

Site geometry

Many landfills are designed solely with the maximum usable volume as the primary criterion. Hence, straight, steep sideslopes are utilized. Practical geometry for efficient landfilling is likely difficult for future development. However, airspace restrictions are usually developed based on height restrictions. The larger the landfill, the larger the relatively flat top of the landfill conducive to development that will be available.

Post-closure care and maintenance

Upon closure of municipal solid waste landfills, owners and/or operators have an obligation to maintain the leachate and landfill gas systems, and stormwater and erosion controls for a post-closure care period. The development of the site for future useful purposes can allow the cost of these provisions to be recovered.

Ownership

The nature of the ownership of the landfill will have impacts on the selection of future land use. Public sector and private enterprise owners have different operating objectives and criteria. Nevertheless, the benefits of future land use can be achieved for either party.

Local resources - local needs

Whether the development is undertaken for profit in the private sector, or for savings in the public sector, the local resources will be directed to meeting local demand. Especially as the local population grows, the public needs for infrastructure take precedence in the case of community-owned landfills. For private facilities, local needs are still paramount, but the ability of the development to yield profit governs.

Development constraints

Regardless of the nature of future land use development, constraints attributed to the composition and nature of the waste will have to be addressed. Protection of the new facilities is necessary to achieve the regulatory and public acceptance of construction on a landfill. All of these constraints have engineering solutions.

Waste decomposition and consolidation

Waste decomposition and consolidation, each of which is manifested as surface subsidence, present the single greatest constraint impacting development. A clear understanding of the materials that were landfilled, daily cover practices, and placement and compaction practices are useful for predicting subsidence (Boutwell and Fiore (1995), Edil *et al* (1989), and Morris and Woods (1989)).

Waste properties related to the nature of the waste streams, such as the proportion of putrescible waste, dictate the degree and extent of consolidation (Landva and Clark, 1989). A clear understanding of geotechnical engineering and soil properties aids the evaluation of these impacts.

Leachate generation

Leachate management is a critical component of landfill operations and subsequent closure. The quantity of leachate generated should decrease significantly upon closure. Although leachate will continue to be collected, the elimination of the water supply by construction of the impermeable cap, will eventually reduce the flows to negligible levels. As a result, the leachate management controls installed to handle leachate during operations will continue to function throughout the post-closure period with minimal maintenance.

Leachate management can continue during the life of the re-development without obtrusion or imposing any particular constraints.

Landfill gas generation

Unlike leachate generated from the waste in the landfill, landfill gas, comprised primarily of carbon dioxide and methane, will continue to be generated in significant quantities for at least 20 years after closure. Air quality and emission controls at landfills generally require the collection and disposal of landfill gas throughout operations and post-closure of the facility. Hence, the measures instituted for landfill gas management must be maintained concurrent with the new development.

Closure infrastructure for the collection and removal of landfill gas routinely consists of horizontal and/or vertical collector pipes, condensate collectors, and a gas flare. It is critical to incorporate the design of these systems into the overall re-development plan, to minimize the redesign and reconstruction of the closure system.

Climate

Climate and weather conditions are an important constraint to future development of landfills. Of particular importance to greenscape developments, such as golf courses, climatic conditions dictate the requirements for irrigation and surface water management.

Golf courses require on the order of one million gallons of water per day, for example. The drainage component of the landfill cap must be designed to manage and recirculate large quantities of water. In arid climates, where many alternative design components are allowed, the cover system will have to be designed to manage this water and conserve it for future irrigation purposes.

Zoning and permitting

Zoning and permitting changes, required for new development above closed landfills, represent the single greatest constraint to this development. Risk averse regulators and a negative public perception with this type of development put the onus on engineers to demonstrate that landfill closures can be safely preserved with the land use, but more important, that the development can be safely constructed and operated in spite of the landfill.

Development options

Landfilling in the era before the present environmental controls was frequently completed in a large number of small facilities. In 1990, there were almost 10,000 municipal solid waste landfills in the U.S., compared to about 20 per cent of that number today. Closure of large numbers of landfills resulted, in many cases, with the development of new, regional facilities, serving the needs of several communities. Many of these newer landfills are several hundred hectares in size. The average large-center landfill, in order to serve the needs of the community for several decades, may need to be over 1,000 hectares in size. In general, associated site infrastructure will result in the site requiring 20 per cent of the land be set aside for that purpose. A 200-hectare landfill footprint will require a 240 to 250 hectare site, to accommodate stormwater management, leachate management, landfill gas management, and operations facilities.

Clearly, the larger the site, the more varied the available options for future beneficial land use. Clearly, for larger sites, multiple and varied land uses are available. In general, available land use alternatives can be characterized as:

- Agricultural land use;
- Recreational land use;
- Open space and habitat land use;
- Commercial land use; and
- Public sector infrastructure land use.

Agricultural land use

Agricultural land use is the most easily implemented alternative, primarily as it does not require the operator to address human health issues associated with occupancy. In particular, agricultural land use can be the default selection for retrofitting future land use, in the absence of pre-planning.

There have been several useful contributions in the study of ecosystems on landfill closure covers. In sites that have been developed for agricultural purposes, studies under way are examining the potential impacts of growing on closed landfills (Ballardini and Lassini (1997), Lassini *et al* (1997)), Lassini *et al* (1999)).

Agricultural development can serve as a beneficial extension of normal post-closure care provisions. Maintenance of the vegetative cover is required through the prescribed post-closure period (normally 30 years). The planting, nurturing, and harvesting of crops can serve to reduce the cost of this measure. Many crops, such as grains, do not require a deep thickness of topsoil to support growth, yet require minimal maintenance during the growing season.

Recreational land use

Recreational land use is the future beneficial development application of landfill space that is selected the most. Of the development-oriented alternatives, recreational land use is the least expensive and easiest to permit. Community-owned landfills are particularly attractive for recreational facilities, such as sportsfields, parks, and playgrounds. In particular, these facilities are attractive due to minimal constraints to the development being imposed by landfill gas control facilities.

Both community and privately owned facilities are developed for golf courses (Fig. 1). Although requiring more of a capital investment, golf courses are revenue-generating recreational facilities, which over time can serve as a source of net revenue that can subsidize other operations, especially for the public sector.

Fig. 1. Few recreational facilities have the spectacular views that are enjoyed from virtually every hole at the Newcastle Golf Course near Seattle on a clear day. This facility is located above a construction and demolition landfill, which in turn overlies a mid-century era underground coal mine.

One of the most significant benefits of recreational development for golf courses and other greenscape alternatives is the resulting visual improvements. In some cases, the aesthetic benefits are spectacular.

Open space and habitat land use

One of the casualties of widespread development is the loss of habitat for common, as well as threatened and endangered species of birds and plants. Implementation of habitat can be simple or complex, depending on the local needs and requirements. In addition to the landfill footprint area, which is suitable for vegetative habitat, other areas can be enhanced to develop wetlands and other habitat serving a wide variety of plant and animal species.

The cost-benefit of open space and habitat land uses may sometimes seem skewed, yet may represent a trade-off with regulators to enhance the viability of a project. The author is presently working on the closure design of an 8-hectare landfill that, upon closure, will be developed as open space designed specifically as habitat for a threatened species of bird, the Western Meadowlark. This area is only sufficient to support one nesting pair of this somewhat territorial bird.

Commercial land use

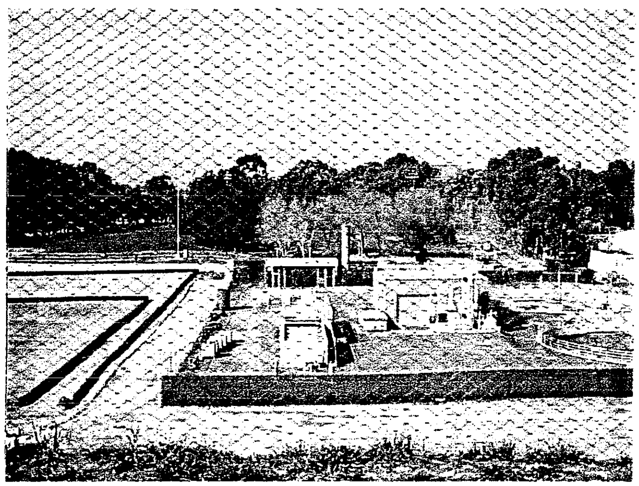
Commercial land use is the most problematic of alternatives. It requires the financial viability of the project, a criterion that may not apply to the other purposes. In addition, commercial land use will frequently involve occupied space. Concerns for safety and protection against landfill gas and other impacts will require comprehensive presentation of the measures incorporated into design that specifically provide protection and controls.

Commercial development involves structures that will usually require non-standard foundation systems. This represents a geotechnical constraint that can be accommodated either during or after the closure construction of the landfill. Other major constraints that particularly impact commercial development include distress to underground utilities or grade-supported floor slabs due to ground subsidence.

Public sector infrastructure(?) land use

Public sector land use, over and above open space and recreational applications, has similar issues and constraints to those for commercial development. Selection of appropriate facilities can, however, be driven by factors other than financial constraints. Large area needs, such as transit bus-parking lots, park and ride lots, and public works supplies storage areas can be attractive options for low-cost land (Fig. 2). They can also be developed without significant concerns for landfill gas impacts, since limited occupied space can be located outside of the landfill footprint.

Fig. 2. Infrastructure provisions, such as this landfill gas flare station can be located or relocated in order to provide a stable foundation and minimal intrusion to recreational and public use facilities.



Many landfills that were sited decades ago were located in remote undeveloped agricultural areas. Today, urban sprawl has surrounded these sites by every type of development. Critical to this growing development is transportation. Hence, a number of landfills have been taken over as a part of highway and urban roadway developments.

Residential - the missing land use

Residential land use will be a potential future land use development. The regulators and the public at large require a much higher confidence level than can be offered now, before residential land use will be allowed on municipal solid waste landfills. This will require more diligent planning for newer facilities to set the stage for residential developments without excessive residual liabilities.

Many developmental factors that input to landfill design will require manipulation to make residential developments attractive, not the least of which is geometry. Geometric design of landfills can be modified from the existing practice aimed at optimizing landfill airspace, without affecting economics or operations. This can still allow closure of the landfill in a manner conducive to single family or multi-family residential development. Until that time, when future land use is a design objective during the landfill development process, the construction of residences on closed sites will be a rare exception.

Zoning will be the greatest obstacle and the caveats that will be applied may be onerous. The care and safety of children will be paramount and will certainly be included in any application process.

Redevelopment and geotechnique

With few exceptions, landfill designers are geotechnical engineers. This is primarily because landfills are large geotechnical structures - embankments and fills placed under compaction and control.

Waste properties

There is a great deal of information on the properties of solid waste in the hands of landfill designers. There is not, however, much information in the literature. Some notable papers have addressed the physical properties of waste (Landva and Clark (1989), Morris and Woods (1989)).

Nevertheless, due to the inherent heterogeneity of waste, site-specific evaluation of waste properties should be undertaken if critical or settlement sensitive structures are planned. Due to climatic and other considerations, moisture content, the key component of both decomposition and consolidation of waste, can vary from almost nil to saturation. Voids and collapsible materials that can lead to significant localized subsidence can be anticipated based on the study of waste receipt, placement, and compaction records from operations.

Site grading and base preparation

Any redevelopment of landfills will require grading of the surface. Care must be taken during the development of facilities that were closed prior to current legislation. The majority of such sites were "grandfathered", in that the existing closure was allowed even when much more rigorous criteria had been adopted. Disturbance of the cap and penetration of the waste surface will be deemed to re-set the regulations. In that case, the site will have to be re-closed in accordance with the current regulations.

In such cases, it is likely that the cover soil thickness varies considerably across the site, since controls applied reflected the leniency of the regulations of the time of closure. The way to avoid this conflict is to develop the final base grade contours through importation of fill. By doing so, consolidation of otherwise normally consolidated waste can exacerbate the potential problems of subsidence that can be expected in any event.

One way to address the subsidence is to stage construction - in effect, preloading the waste. As the feasibility of any development is linked to its timing, this may or may not be acceptable, or at least may revise the alternatives available for redevelopment. Again, a clear understanding of the characteristics of the waste is essential to evaluate the impacts and consequences of revising site grades.

Building foundation support

The foundation support of buildings above compressible soils is a well-documented, well-understood component of geotechnical engineering. Although it is much more difficult to predict the consolidation of waste materials, the concepts and approaches taken to overcome the constraint are similar to that for soils. Depending on the thickness of the waste, pile foundations may be a solution for structural support, and in extreme cases, structurally supported grade slabs.

Methods of consolidation used for soils are also available. Preloading may be a practical alternative depending on the scheduling of redevelopment construction. Dynamic compaction has also been employed, but is subject to the same considerations as for soils. If these procedures can be effectively applied, then shallow foundations, or raft-type foundations that spread the load uniformly may be appropriate.

In truth, foundation support is the most straightforward of geotechnical considerations associated with buildings constructed above landfilled areas. Wherever possible, the first preference will still be to distribute the structures so that they occupy the areas beyond the landfill footprint. Nevertheless, the technology and expertise is widely held to support structures above the waste.

Underground utilities

If buildings could stand alone with no other connections, then the bulk of the constraint would be satisfied with the foundations. Of course, that is not the case. Utilities are necessary to support any type of building, including water supply, storm and sanitary sewer, and power. These are all buried utilities. It is preferable not to place the service corridors beneath the roads or other paved areas, wherever practicable. In fact, where allowed by local regulations, collection of all of the utilities in a subgrade utilidor would be a desirable alternative. Of course, that case could also be made for normal construction.

Roads and parking areas

The greatest concern for the performance and integrity of roads and other trafficked areas, such as parking lots, is for differential movements that can destroy the continuity, grades, drainages, and surfacing of these paved areas. The construction of roads over soft, compressible soils is not an unreasonable challenge to the geotechnical engineer.

However, the best way to construct those roads and traffic areas is to avoid locating underground utilities beneath the roadway right-of-way. By doing so, it is possible not only to develop the subgrade condition in as uniform a manner as possible, but also to utilize available methods, such as reinforcement geosynthetics, to mitigate the potential effects of differential subsidence. Control of surface drainage of stormwater must be more flexible than usual, but aside from larger than usual surface gradients, those systems can be designed using conventional practices.

By distributing the loads over as wide an area as possible, the potential impacts of differential subsidence of the waste surface can be buffered. The design concepts are similar to the construction of roads above very soft soils, recognizing that the underlying materials may be heterogeneous. This is a classic example of the type of situation that geotechnical engineers routinely face, i.e., recognition that poor subgrade conditions, in this case complicated by the existence of the waste, is simply a constraint. As always, once the constraints are identified and understood, design can proceed to accommodate them.

With this knowledge, pavement areas can be effectively designed to stand up to both traffic loading and uncertain distribution of ground movement. Fig. 3 illustrates an example of a parking lot above a landfill. Most land uses require roadways and parking lots, including those for which the primary land use requires paved areas, such as public works storage yards, bus parking for community transit, and park and rides.

Geotechnical constraints on development

All of these considerations require a more involved contribution from the geotechnical engineer than normal site development. It is critical that the facilities designers and the site civil design engineers recognize the importance of the geotechnical engineer. As with all such construction, it is possible to construct these components of the development in a conventional manner, but in short order, the consequences will be apparent.

The regulators responsible for project approval and permits will likely want a detailed demonstration of the efficacy of any design measures selected for this type of development. Owners will want assurances that their facilities can be expected to have normal or at least comparable service lives to ensure the feasibility and viability of the projects. Maintenance and support services will in most cases be required at a premium to normal developments, but this should not be a factor in the decision to proceed. Cost implications will be mitigated by the reduced cost of land, which is a location and market-specific constraint.

Fig. 3. Asphalt surfaced parking areas are an economically attractive land use for construction above landfills for park and ride facilities.

Geosynthetics

The use of geosynthetics, mentioned previously, is another big contribution to the development of marginal land. The use of reinforcement geosynthetics, such as geogrids and high strength geotextiles, to span soft ground and other subsurface irregularities, has become the state of practice. These methods are equally appropriate for subgrade stabilization above waste, and beneath pavements and other trafficked areas.

Geosynthetics such as composite drains and geotextiles will also be beneficial for drainage provisions, especially for landscaped areas that will require irrigation. The control of surface water that is a critical component of closure design will remain with any future land use above closed landfills. Trickle irrigation and/or controls that strictly regulate the amount of watering provided will be necessary. In addition, climate controls that terminate watering on rainy days should also be included.

In some cases, it may be desirable to line drainage ditches and other areas with geomembranes, to more effectively control the runoff of surface water and inhibit infiltration to the closure drainage system.

Considerations for redevelopment

Conventionally associated with the post-closure aftercare period for landfills is the prohibition of the site from future land use. This is a luxury that we can no longer afford. Many geotechnical challenges to the potential future land development uses remain. However, the problems that appear to be associated with redevelopment are simply the product of perception of those constraints.

Those constraints can be minimized by extension of the planning process back to the facility development stage. Selective geometry of cell development, waste placement operations, and non-conventional closure configurations can be utilized to enhance the opportunities for beneficial future land use. A close understanding of the properties of decomposing waste is also essential to the planning process.

Most of the post-closure developments that have been accomplished to date were for landfills or related contaminated sites that were in place at the time of conception. In those cases, the site-specific constraints of geometry, geology, waste stream characteristics, landfill operations issues, and closure will govern the concepts and alternatives available to the developer.

In the future, redevelopment of closed landfills should become the default opportunity. This is totally keyed to the planning process, and changes our conventional approach to design, operations, and financial evaluation of landfills.

Planning: the key tool to success

When future land use is inserted into the landfill planning process at the concept stage, it quickly becomes apparent that every aspect of a landfill's life is significantly impacted by the idea of using the land after closure. These parameters and their importance to the process are presented below.

Regulations

In the U.S., municipal solid waste landfills are regulated by the individual States. Each State's regulations are predicated on the federal law known as Subtitle D (Code of Federal Regulations, 1993). The State laws vary, but must meet as a minimum, the criteria delineated in the federal regulations. Included in these regulations are strict requirements for closure design and for post-closure financial assurance.

This regulation applies specifically to municipal solid waste landfills, but related law addresses facilities such as construction and demolition landfills and other permitted facilities. In the regulations are specific requirements for closure as well as post-closure care and maintenance, and associated financial assurances that these provisions shall be met for at least 30 years.

The regulations in Washington State, in WAC 173-351-600 Financial Assurance Criteria, require owners and operators of all municipal solid waste landfills, to *"establish financial assurance for closure"* of the facility. In addition, *"financial assurance...must account for the total costs of conducting post-closure care, including annual and periodic costs as described in the post-closure plan over the entire post-closure care period"* (Washington Administrative Code, Chapter 173-351, 1993).

These costs are significant. The majority of landfills have been closed with these criteria in place. The liability and expense accruing to these sites is great - the consequences of problems in the future even greater.

When controls are imposed during a site redevelopment, revenues from the new development can offset these costs. Operations and maintenance costs attributable to the redevelopment, such as landscaping maintenance, can replace the obligation for that in the post-closure plan, and in fact transfer those costs to the tenants.

Site selection

Site selection criteria for new landfills usually focus on minimal impacts to the vicinity and region, including traffic. Adequate roads are essential to landfill operation, but are also essential to contiguous future development.

As attractive and often uncontroversial as truly remote sites may be during the siting process, they do not make desirable candidates for future site development. Planning for future land use that will not commence until some time after closure will similarly detract significantly from the appeal of the concept. Thrusting benefits too far into the future will tend to diminish the enthusiasm of the owner for the reality of the benefit.

It may be that the underlying criteria for initial site selection are insensitive to the additional parameter of future land use. If the landfill is not viable, cannot be permitted, or has excessive cost at a given site, the future benefit of alternative land use is irrelevant. The feasibility of the principal project on a site will survive any other constraints or distractions from the point of the project in the first instance.

Site layout and design

Site layout, design, and selection of the landfill footprint are absolutely critical to the most efficient future land use. One of the input parameters to landfill conceptual design is the total airspace, which dictates the effective life of landfilling operations. If the concept can be developed so that airspace needs can be economically satisfied in a geometry that may not be purely efficient from an engineering viewpoint, then more options become available.

For example, having multiple crests of the landfill, and at different elevations, can make a facility such as a golf course more aesthetically attractive. Similarly, a curved footprint can be incorporated into the total site development without compromising the cost effectiveness of the design, or hindering site operations. As engineers, we need to set our straight edge aside from time to time. With the sophistication of CAD systems available today, designs without straight lines are routine. Constructing them is more of a challenge, but not a constraint.

Closure design

Closure design needs to meet the criteria outlined in the regulations. In almost all cases, however, these criteria are defined as minimum requirements. For example, final grades on a closed landfill must *"address anticipated* *settlement (with a goal of achieving no less than two to five percent slopes after settlement)"* (WAC 173-351-500(1)(a)(i)(D)). As long as the capping system can be designed and constructed with functional surface drainage, there is no restriction on slopes, as long as they meet the minimum criteria. In fact, not all slopes necessarily need to be directed toward the perimeter.

Landscaping must be accommodated on the closed landfill. Unless grass is planned everywhere, some areas will need to be contoured to provide for root balls of trees and shrubs. All of these criteria are mere constraints. Engineers designing closures must understand these constraints, along with the needs for the redevelopment. Almost any scheme can be adopted that will provide effective future land use, often without apparent visual evidence of the presence of the former facility.

Permitting

The feasibility of any redevelopment, from both technical and economic viewpoints, is irrelevant if it can not be permitted. Landfill owners are all too aware of the benefit of an informed and educated public. Similarly, the people responsible for providing zoning and permits to construct these facilities must be similarly informed. Although many post-closure land use developments have been completed successfully throughout North America, it is most likely that in a given jurisdiction, it is a totally new concept.

Landfills generally fall under the jurisdiction of the State Department of Ecology, Environmental Protection, or Environmental Quality. The permit reviewers are usually engineers or other professionals that understand landfills and environmental issues. However, the actual solid waste operations permit usually comes from the County Department of Health. Their focus is typically on human health, rather than on technical issues, that being human health.

Even so, post-closure permits will likely come from the County agency responsible for development, that routinely review grading and drainage permits. They will likely not have seen this type of application before. So the engineer's challenge is to sell the concept to both the State agency providing technical review, but also to the local permit reviewer, for whom the entire notion is bizarre. All of these parties must be convinced of the efficacy of the concept and design, but clearly at different levels.

Permitting is the challenge. We have the technical skills to design almost anything almost anywhere, and construct it safely and lastingly. Now we have to convince the powers that have the ability and authority to say No. With good planning at all stages, this is only another, although formidable, constraint.

Successful redevelopment

Landfills have been redeveloped since the dawn of man, long before it occurred to us to regulate waste disposal. In fact, even in the urban Pacific Northwest, in the City of Seattle, there are at least ten or twelve old landfills within the City, near downtown, the University of Washington, and other developed areas. These landfills predate any vestige of regulations governing their operation.

In many cases, development was completed without consideration of the constraint. The Interbay Golf Course, in Seattle's Magnolia neighbourhood, overlies the Interbay Landfill, which was operating in the 1960's. Prior to our present-day regulation, it is likely that no particular restrictions were placed on that development.

But this is the new century. Many landfills are being built upon, which exhibit a level of sophistication not previously envisioned.

Golf course and resort developments

Golf courses are a popular redevelopment option for landfills for a variety of reasons. The average site available is often just the right size. Occupied space, a major concern of the regulators, is minimized. Landfill gas and leachate issues can be addressed with little or no impact on the functionality of the development. And if the landfill is high enough, views may be particularly good. Aesthetics and playability are key criteria for golf courses. Many landfill sites provide these.

One of the most prominent developments, that has now been operating for over ten years, is the hotel and resort in the City of Industry, California. Two PGA calibre golf courses and a major hotel are located on the site.

In the Seattle, Washington area, the Newcastle Golf Club opened in 2000, located above a construction and demolition landfill, which in turn overlies an old underground coal mine. Prior to development, many issues had to be resolved associated with both the landfill and the mine. Today, however, it is a development with a first rate clubhouse (Fig. 4) and two championship calibre courses. In addition, it has spectacular views of Seattle and the Olympic Mountains (Figs. 5, 6).

Fig. 4. The clubhouse at Newcastle Golf Club had many geotechnical constraints that were overcome.

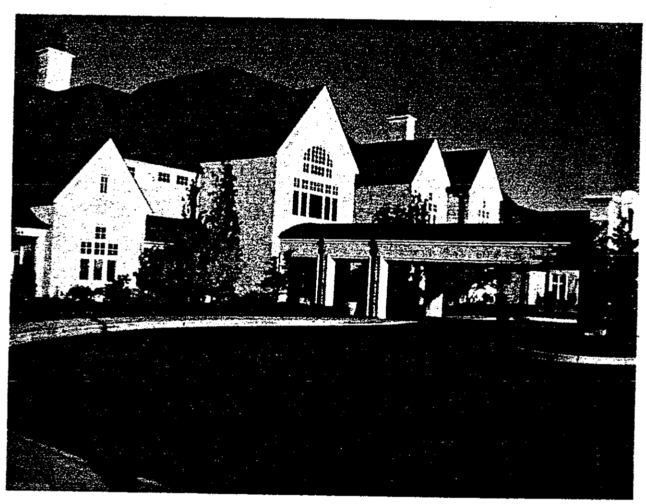


Fig. 5. Views and aesthetics are critical to a first-rate golf facility, such as Newcastle Golf Club near Seattle.

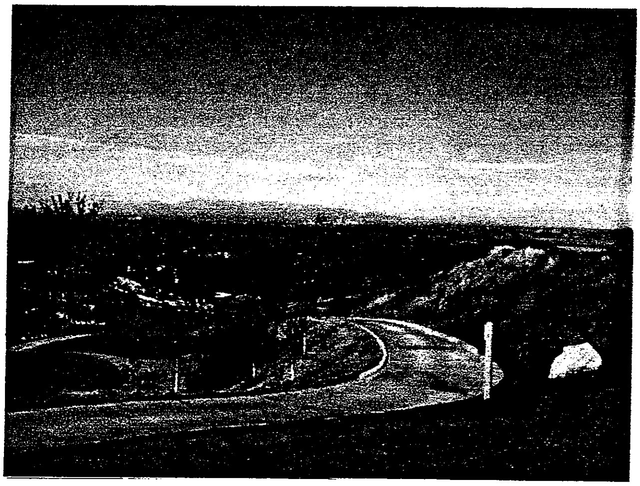


Fig. 6. The City of Seattle and the Olympic Mountains make a great backdrop, challenging golfers at Newcastle.

Grading at Newcastle was simplified somewhat because of discontinuous landfilling and existing grades at the site. This allowed contouring to be developed that enhanced the playability of the courses (Fig. 7).

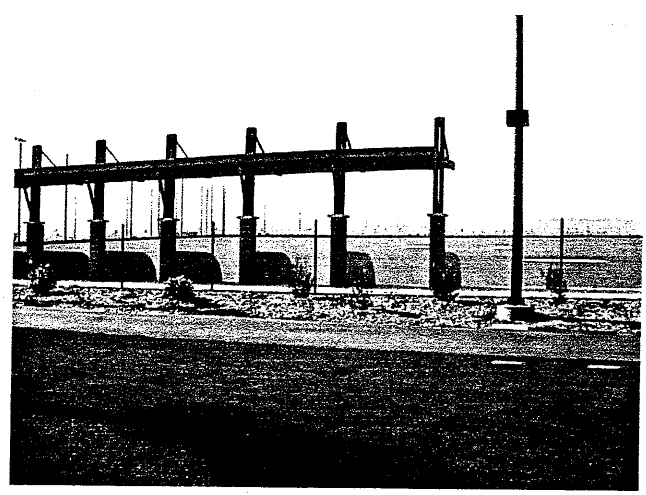
Recreational development

Another effective example of productive future land use was created at the Burlingame Landfill, in Burlingame, California. A City-owned facility, it was desirable to create recreationally-oriented land use for as wide a cross section of the people as possible. The facility, opened in 2000, has playgrounds for youngsters (Fig. 8) and a golf driving range for all ages (Fig. 9). Baseball diamonds and soccer fields provide badly needed facilities for organized sports. With the cost of land in the Bay area at prohibitive levels, the value of these facilities is enormous.

Fig. 7. The ability to conduct significant regrading and use interesting natural contours effectively masks the previous land use at Newcastle.

Fig. 8. Playgrounds provide much needed areas for youngsters to have fun safely off the street.

Fig. 9. Practice for future redevelopments over existing landfills is available at Burlingame's golf driving range.



Imagination and expertise

Geotechnical engineering expertise, combined with foresight and imagination are the key elements of creating usable land in areas previously abandoned after use. It takes a wide spectrum of capabilities to develop these sites, but co-operation and planning will continue to be the most important factors.

The concepts and considerations for landfill redevelopment apply equally to a wide range of formerly derelict land. As land values increase, the demand will provide an incentive for the creativity needed to get innovative and exciting projects accomplished. The benefit of reclaiming this land speaks for itself.

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