THE FEASIBILITY OF CONSTRUCTING SOLID WASTE LANDFILLS AS A RECLAMATION METHOD FOR ABANDONED MINE LANDS[1]

Dr. Louise H. Michaud[2] and Mr. David Bjork[3]

Abstract: Solid waste production is increasing, while available landfill space is decreasing due to increasing environmental protection legislation and public opposition. One possible solution to this problem is to locate landfills in abandoned mine sites. If conducted in an environmental safe manner, this practice can provide a means of reclaiming abandoned mines and of improving the water quality at these sites, it can generate needed revenue and jobs in economically depressed mining areas, and it can ensure needed landfill space for the future.

Twelve case studies of landfills developed in abandoned mines in the US and Canada were investigated. Each site was evaluated and compared based on its success or failure in relation to the design, geologic and hydrologic setting and water quality control. This study shows that, where properly designed, situated and managed, landfills located in abandoned mines do not result in a deterioration to the surrounding environment or water quality.

Key Words: Reclamation, Landfills, Abandoned Mine Lands, Solid Waste Disposal

Introduction

History of U. S. Federal Solid Waste Disposal Legislation

Over the last twenty years, the rate of solid waste production in North America has grown much faster than the rate at which new disposal facilities are developed. Changes in the environmental protection regulations and increased public opposition to landfill developments have made it increasingly difficult to construct new waste disposal sites.

Solid waste disposal legislation in the United States began in 1899 with the Rivers and Harbors Act. Since then, legislation has developed to improve solid waste disposal practices and to reduce environmental degradation. The Resource Conservation and Recovery Act (RCRA) of 1976, was enacted for the protection of human health and the environment and required that waste be disposed in a more environmentally acceptable manner. This legislation prohibited the open dumping of solid waste on the land and required that existing open dumps be converted into facilities which do not pose a danger to health or the environment (Pffeffer, 1992).

In the United States, nonhazardous solid waste disposal is currently federally regulated by Title

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[1] Paper presented at Sudbury '95, Conference on Mining and the Environment, Sudbury, Ontario, May 28th - June 1st, 1995.

[2] Dr. L. H. Michaud, Assistant Professor, Department of Mineral Engineering, The Pennsylvania State University, University Park, PA 16802-5000.

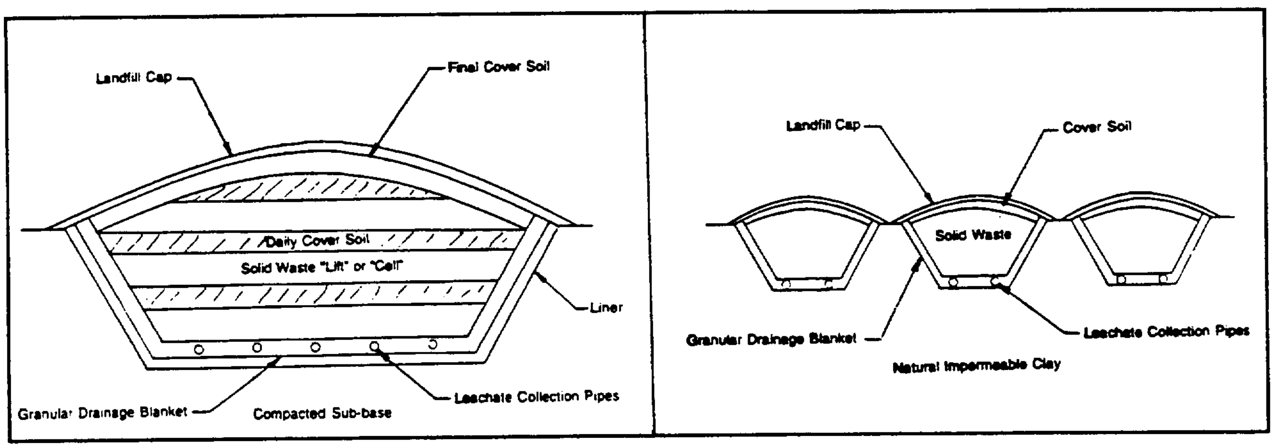
[3] Mr. David Bjork, Masters of Environmental Pollution Control, The Pennsylvania State University, University Park, PA 16802-5000.

40 of the Code of Federal Regulations (CFR) and the RCRA Subtitle D. These regulations outline general performance standards, requirements and recommended procedures for locating, permitting, and operating a solid waste landfill. They also set the minimum performance standards which each state must follow (Federal Register, 1988).

Design of Solid Waste Landfills

Sanitary landfills was popularized in the early 1960s in an effort to solve the air pollution and vermin problems associated with open dumps. The use of soil to cover the surface of the landfill was well established by the late 1960s, but this practice did little to prevent groundwater and surface water contamination. Since this time, landfill design concepts have gradually evolved to overcome the shortcomings of previous designs.

There are presently two main types of landfill designs, the area landfill, the most common method of solid waste disposal, and the trench landfill. Current regulations require that all solid waste landfills to be equipped with at least one impermeable liner, a leachate collection system, a gas collection system and an impermeable cap (Ham, 1993). The main design features of these two landfill designs are illustrated in Figure 1.



a) Area Landfill b) Trench Landfill

Figure 1: Design Criteria for Landfill Construction.

The characteristics of the local soil is an important consideration in selecting a landfill site. Earthen materials are used to construct the sub-base, the daily, intermediate and final cover layers, and the clay liners and caps. If suitable local material is not available, it must be imported, often at great expense. A second important consideration is the protection of groundwater resource. Based on Environmental Protection Agency (EPA) and municipal reports from several states, groundwater contamination has been the most significant problem associated with waste disposal sites and should be the primary concern in siting and permitting new landfills (Ballestero and Kelley, 1990).

Local conditions that must be taken into account when designing of a solid waste landfill include the permeability and hydraulic conductivity of the landfill sub-base, groundwater flow characteristics and the distance between the base of the landfill and the groundwater table. In the event of a failure in the landfill liner system, it is the landfill sub-base which controls the movement of leachate and landfill gas away from the landfill. Solid waste landfills should therefor be located in areas of silt and clay soils which restrict fluid movement or over thick deposits of dense, impermeable rock. Areas with highly permeable soil formations or fractured bedrock are therefore not suitable for use as waste disposal sites.

Groundwater flow characteristics determine how far and at what speed contaminants will be transported away from the landfill site. This is affected by the hydraulic conductivity of the ground and whether the site is in a groundwater recharge or groundwater discharge area. Permeable formations such as sand, gravel deposits and fractured rock increase the rate and extent of water transport and therefor increase the potential for uncontrollable groundwater contamination is great.

The distance between the base of a landfill and the groundwater table should be maximized. As well, It is advantageous to have a layer of impervious rock between the landfill and the groundwater table in order to reduce the risk of contamination. Additional factors that must be considered when locating a solid waste landfill include the surrounding land uses, the potential for public opposition, proximity to waste producers, site access, and available area for development.

Benefits of Siting Landfills in Mined Lands

Economic Benefits to Local Communities

The closure of a mine can cause severe economic problems for the communities near the mining area. Reclamation of a mined area through the construction of a solid waste landfill can offer many benefits to these communities, if the landfill is properly designed and maintained. This can include economic benefits to the community by creating a use for land which was previously devastated, revenue for the community, county, and state in the form of taxes and tipping fees, and employment opportunities in an area which was negatively impacted by mine closure.

Rehabilitation of Abandoned Mine Lands

The development of a solid waste landfill in an abandoned mine can also be beneficial to the local environment as it can accomplish many of the goals of a standard mine reclamation program, at no cost to the government. The construction of the landfill liner and solid waste lifts will bury the steep highwalls. Where suitable, using spoil piles as a source of daily cover material will place the spoil inside the landfill and lead to a gradual levelling of the spoil piles, returning the surface to its approximate original grade. Because solid waste disposal regulations require a landfill cap to be covered with a suitable topsoil and seeded, a landfill constructed in an abandoned mine will also result in a well-vegetated landscape in an area that may have been relatively barren for many years (25 P Code, 1992).

Improvements in Water Quality

Abandoned surface mines are an incessant source of water pollution. The major water pollutants associated with coal mines is acid and high concentrations of iron, manganese, and other heavy metals. Metal mine drainage may also contain toxic concentrations of other heavy metals and trace elements. Unstable, poorly vegetated mining areas also contribute to water pollution through erosion and sedimentation.

Because solid waste disposal requires the construction of impermeable liners and an impermeable landfill cap, surface water infiltration through the site is greatly limited. Revegetation of the site will also reduce erosion at the site and sedimentation in nearby surface waters. The requirements for the installation of clay or synthetic landfill liners and a leachate collection system also reduces water entering the landfill and prevents water from percolating below the landfill liner.

If the characteristics of the mining spoil are suitable for use as a daily cover material, the use of overburden as a cover material for the landfill will also reduce the generation of Acid Mine Drainage (AMD) at mine sites that contain sulfur bearing materials. Because this procedure places the acid-producing material inside the landfill, it is taken out of contact with the atmosphere. Any AMD that is formed will be collected in the leachate collection system where it can be controlled and treated.

Excessive erosion is also common at abandoned mine sites, due to the exposure of large tracks of unprotected soil. This is intensified when surface runoff of storm water is heavy and uncontrolled. The requirements for a vegetative cover and runoff control devices at a waste disposal facility greatly reduce the sedimentation and suspended solids problems of nearby surface waters.

Protection of Higher Quality Land

The increasing strictness of government regulations and organized public opposition make it increasingly difficult to find suitable waste disposal sites. The geologic and hydrogeologic conditions necessary for safe solid waste disposal are often found on irreplaceable prime farmland, a resource that is in short supply. Using unreclaimed mined land that has little economic or ecological significant would be more desirable for solid waste disposal than using prime farmland.

Advantages to Landfill Operator

The size of a landfill site is critical because it determines how large of an area a landfill can serve and for how many years. Many abandoned mines cover large tracts of land that are capable of holding millions of tonnes of solid waste and generate millions of dollars in revenue. For example, an excavated pit that covers one hectare (10,000 m^2) and is 20 m deep can hold $200{,}000^3$ of material. Of this total, 80 % is solid waste. If the landfill tipping charge is \$50/m^3 (tipping fees for municipal solid waste disposal range between \$20/m^3 and \$100/$m^{3)}$, this one hectare pit will gross about \$8 million in revenue. Construction and maintenance costs for a landfill are about \$1 million per hectare (Weaver, 1991).

The road system and infrastructure created by a mining operation is quite conducive to solid waste disposal. Accepting waste by railway is also a possibility, especially if a rail system is already in place for the mining operation. Shipping solid waste by railway is a growing trend in the waste disposal industry because it allows landfills to accept more waste, to accept it from farther away, and operate on a larger scale.

The types of soils present at a potential landfill site is one of the most important cost considerations for a landfill operator. Although it may be necessary to screen the material to make it suitable for use as a landfill construction material, most mine sites have an abundance of spoil material. At many sites, this material is suitable for use as daily cover and as landfill base material.

Potential Problems of Siting Landfills in Mined Lands

Degradation of Water Quality

While there are several advantages to siting solid waste landfills in formerly mined areas, there are also potential problems which must be considered. Protection of groundwater supplies is always of great concern. Mines often have fractured rock floors and sidewalls due to blasting which offer little resistance to leachate movement in the event of a liner failure. Many surface mines pass through the groundwater table and create a condition where the pit is continually flooded. As well, many mines are sited in groundwater recharge areas, creating an environment where contaminants are quickly dispersed over a wide area. Groundwater management is therefore an essential landfill design consideration for a mine (Goodings and Schram, 1985).

Subsidence of Underground Mines

Development of a landfill in an area where underground mining has been conducted is more expensive because of the potential of subsidence. In these areas, extensive site investigation is required to locate all underground workings and to determine the potential for subsidence. Landfill construction may be possible in areas where the mining took place far below the surface. However, shallow underground mine workings are more prone to abrupt, complete subsidence and the potential for damage to landfill structure is significant. These areas should be avoided by landfill developers (Ivey, 1978).

Landfill Construction Problems

The material available at a mine site may contain a large percentage of boulders and may not meet permeability requirements unless it is further crushed and /or screened. As well, spoil at some coal strip mines may be too carbonaceous for use as a landfill daily cover material. This material is undesirable due to its flammability and the inability to control fires inside the landfill. Pennsylvania regulations will not allow the coal content of daily cover to exceed 12 percent by weight (25 Pa. Code, 1992).

Landfills cannot be located in areas that are inhabited by endangered or protected species including abandoned mine areas. Nor can solid waste landfills be sited in wetland areas or over aquifers that are used as public water sources.

Public Opposition

Public acceptance is a very important factor in successful implementation of a solid waste disposal plan. Although generally there is opposition at using high quality land as landfill sites, public opposition may be even greater in abandoned mining areas. Communities that have had to deal with environmental problems related to mining activities will not want to face the potential threat of further environmental damage caused by a poorly managed solid waste landfill in their area.

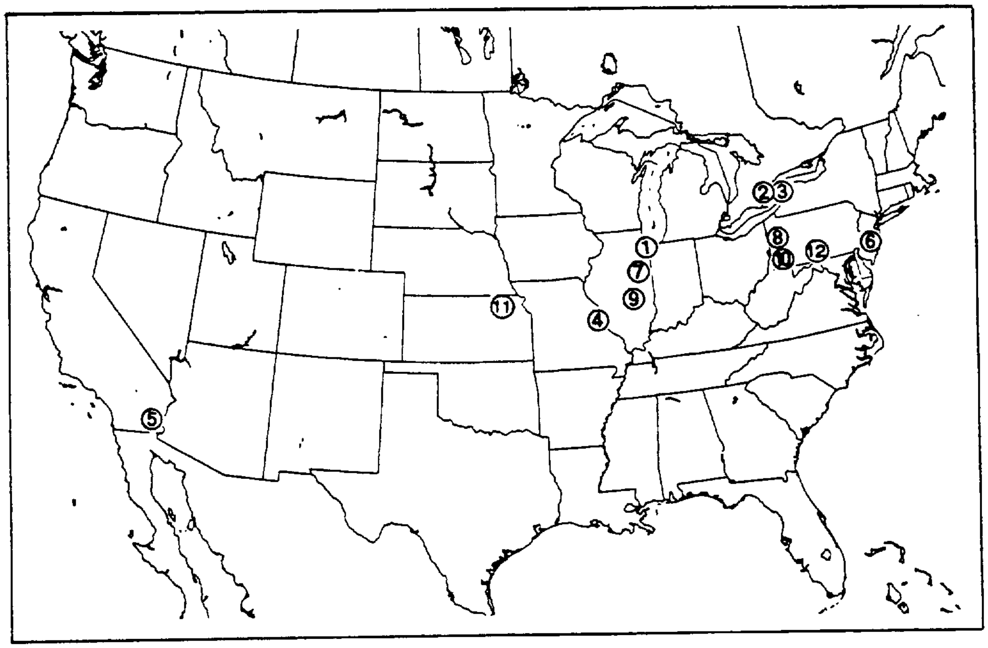
Case Studies

Selection of Landfill sites

An investigation of technical publications and government documents was carried out to identify areas in North America where solid waste landfills were constructed in previously mined areas. In total, twelve sites were identifies and chosen for analysis. These include 4 landfills constructed in quarries, 1 in a metalliferous open pit mine, 2 in non-indurated material mines and 5 in surface coal mines. Some of these landfills were constructed in abandoned mine sites, while others began development prior to or at closure of the mine. The names and locations of the landfill sites is illustrated in Figure 2. A detailed description of each of these sites, including landfill construction and operating practices, can be found in Bjork (1994).

Evaluation Criteria of the Landfill Sites

Each landfill site was evaluated for a variety of properties, including hydrological properties, soil characteristics and physical features of the site. Other evaluation criteria include the age of the



Locations of Case Study Landfill Sites

1. Quarry - Congress Development Co. Landfill, Hillside, IL
2. Quarry - Niagara Waste Systems Ltd., Thorold, Ontario
3. Quarry - Glenridge Quarry Waste Disposal, Niagara Falls, Ontario
4. Quarry - Fred Weber, Inc. North Quarry, Maryland Heights, MO
5. Iron Ore Mine - Eagle Mountain Landfill Project, Eagle Mountain, CA
6. Clay Pit - Parklands Reclamation, Bordentown, NJ
7. Sand-and-Gravel Pit - DuPage County Blackwell Forest Preserve Landfill Project, Warrenville, IL
8. Coal Mine - West Side Sanitary Landfill, Plymouth Township, PA
9. Coal Mine - Gallatin National Balefill, Fairview, IL
10. Coal Mine - Duquesne Light Landfill, Elizabeth Township, PA
11. Coal Mine - Linn County Landfill, Prescott, KS
12. Coal Mine - North Mountain Landfill, Mahanoy Township, PA

Figure 2: Location of Case Study Landfill Sites

landfill site, size, landfill construction techniques and the types of waste accepted. An analysis of the characteristics of these landfill sites and a comparison of the successes and failures associated with the sites was then carried out. Qualitative comparisons were also made between the landfill sites of each different mine type. The main purpose of this evaluation was to determine which characteristics make a mine site suitable or unsuitable for use as a solid waste landfill. Although this includes the economics of operating a landfill, the main criteria for success is the protection of the environment.

Analysis of Quarry Sites

Although most quarries are not suitable for waste disposal because blasting practices create fractures in the quarry floor and walls, all of the case study landfill sites located in quarries have been successful in controlling environmental contamination. These landfills are generally well-planned and well-designed and a great deal of care is taken in site selection and site preparation. They benefit from modern landfill construction techniques and advanced design and operating concepts. The major factors that make each site suitable for waste disposal are the control of groundwater resources, competent landfill liners, and efficient leachate handling.

At each of the quarries, systems have been engineered to control groundwater flow and to prevent environmental contamination. Three of the four quarries are located in groundwater discharge zones, thereby containing potential leachate leaks within a localized area. Two of these sites also have engineered trenches below the landfill liners to control groundwater flow through the site. The fourth quarry landfill site uses pumps to control groundwater flow below the landfill.

All of these landfills were also constructed with excellent liners. Either thick natural layers of impermeable shale or clay liners constructed of materials recovered on-site. At three of the four sites, leachate is pumped directly from the landfill site to a local treatment facility. The fourth quarry site is currently shipping leachate to a local treatment plant by truck, but is taking steps to pump it directly.

The only problem that any of these landfills have faced is obtaining enough daily cover material on-site. Because most quarrying operations leave little spoil material on site, at three of the sites, additional cover material such as soil, paper mill sludge or spent foundry sand had to be imported (Goodings and Schram, 1985). At two of the quarries, mining and landfilling are carried out side-by-side. This allows overburden removed for quarrying to be placed directly into the landfill for use as a cover material, eliminating stockpiling. The Glenridge and Fred Weber landfill operations have also made strong efforts to keep good relations with the surrounding communities, including consulting the community for possible end uses of the landfill, and refusing to accept hazardous or special wastes, to avoid potential conflicts with the public.

Analysis of the Metalliferous Open Pit Mine Site

Only one landfill was found in a metalliferous open pit mine and this site has only been in operation for a short time. The Eagle Mountain Landfill Project is the newest landfill site of all of the case studies and indicates a trend toward very large landfills to take advantage of the economy of scale. Initial indications are that this state-of-the-art landfill facility is well designed and should be very successful. It is located in a remote area in the Mojave Desert, and is therefore subjected to far less public opposition than sites located in highly populated areas. The risk of groundwater contamination is also very small. The area receives little rainfall and the distance between the landfill base and the water table is very great. This landfill operation should have little environmental impact over its lifespan.

Analysis of Non-indurated Material Mine Sites

Of the two case study landfill sites located in non-indurated material mines, the Parklands Reclamation, located in a clay pit, has been successful in controlling environmental contamination, whereas the Blackwell Landfill Project, located in a sand-and-gravel pit, was not. This indicates the importance of site selection in landfill design and construction.

The sand-and-gravel pit is unacceptable for waste disposal by today's standards. The site is located in a groundwater recharge zone, the landfill extends into a highly permeable glacial outwash aquifer, and the site is virtually surrounded by bodies of surface water. This landfill extended below the layer of clay till that was meant to act as a liner, into areas of highly permeable materials, and the leachate collection system that was designed was never built. The landfill was constructed in the

1960s, when federal law did not require the environmental protection systems found in today's landfills. Conversely, the successful Parklands Reclamation landfill, located in a clay pit, is located above the water table in an area of highly impermeable clay soil which prevents leachate migration. This landfill was constructed with an exceptional natural clay liner and a leachate collection and recirculation system.

Analysis of Surface Coal Mine Sites

Of the sites studied, the landfills located in surface coal mines had the lowest success rate. Three of the five sites caused some degree of groundwater contamination. The Gallatin National Balefill and the Duquesne Light Landfill have been successful in controlling environmental contamination. These landfills are well-planned, well-designed, and have been operated properly. The Gallatin National Balefill is a state-of-the-art facility, with a highly advanced groundwater control system (with an engineered inward pressure gradient), a competent landfill liner, and a leachate collection and recirculation system. This site is also very large to take advantage of the economy of scale. The Duquesne Light Landfill, uses advanced waste treatment procedures to allow safe disposal of a special waste, cemented fly ash and coal combustion scrubber sludge. Both of these sites also considered public interests.

The failure of the other three surface coal mine sites can be attributed to poor site selection and landfill design, improper operating procedures, and the age of the landfills. Two of these landfills were constructed before federal law mandated strict environmental protection systems. The North Mountain Landfill, was constructed without a liner or a leachate collection system, and the Linn County Landfill's liner, a natural shale layer, was not continuous under the landfill and allowed leachate migration. Also, little regard was given to the hydrogeological setting at these sites. These sites are unsuitable for waste disposal by today's standards. The third site, the West Side Sanitary Landfill, is fairly modern and is equipped with two liners and a leachate collection system. However, groundwater contamination occurred at this site due to poor operating procedures. This facility was overfilled and waste was placed outside of the edge of the liners, allowing leachate to travel into groundwater system.

Generally, there are more potential problems for a landfill developed in an abandoned coal strip mine than in other types of mines. Coal strip pits often intersect old deep mine workings which, along with fractured rock floors and highwalls, can cause uncontrollable groundwater flow patterns. The risk of subsidence must always be considered. The suitability of coal mine spoil for use as a daily cover material varies from site to site and is dependent on the particle size distribution and on the percent coal in the waste rock.

Evaluation of the Success of the Case Studies

Evaluation Criteria

The landfill sites were compared with each other to determine if one type of mine proved to be superior to the others for solid waste disposal. An evaluation system was developed where each landfill site was judged on a pass/fail basis for eleven design and operating considerations. These criteria include:

Groundwater Protection: the groundwater is protected by engineered flow systems, there is a large distance between the landfill base and the water table, or there are waste treatment processes in place to reduce leachability.

Design Quality: the landfill is well-designed, with proper environmental protection systems, proper siting, and good hydrogeological location.

Quality of Construction and Operation: the landfill is built and operated according to the designer's specifications and does not cause environmental contamination.

Liner On-Site: the materials required for liner construction were naturally available at the landfill site. (A landfill was not given a passing grade if the liner materials found on-site did not prevent leachate transport).

Cover On-Site: an adequate amount of suitable daily cover material was available at the site. The landfill operator did not have to purchase additional daily cover material.

Leachate Management: leachate is handled safely and efficiently at the site. Provisions have been made for pumping leachate directly to a treatment plant and/or leachate is recirculated back into the landfill.

Waste Reduction: waste is recycled, baled, or treated in some way to reduce volume and maximize landfill space.

Public Relations: the landfill operator has made a strong effort to maintain good relations with the host community through public meetings and/or providing a final land use that is well-suited to the community.

Economy of Scale: the landfill is very large and can accept large amounts of waste to offset the cost of the environmental protection systems and operating costs.

Side-by-Side: mining and waste disposal are done contemporaneously to maximize resources.

Access: the landfill can be accessed easily by a major highway or railroad.

The results of this evaluation are summarized in Table 1. If a landfill site performed commendably for a given judgment criterion, the site was given a passing grade and the appropriate space in Table 1 was marked with a '+'. A site was also given a passing grade for a judgment criterion if conditions existed such that an environmental protection system was not required for safe operation of the site. If a landfill site performed poorly or the judgement criterion did not apply to the site, the space was left blank.

Mine Type	Name of Site	Judgment Criteria [1]											Total	Average for Mine Type
		Groundwater Protection	Design Quality	Quality of Construction and Operation	Liner On-Site	Cover On-Site	Leachate Management	Waste Reduction	Public Relations	Economy of Scale	Side-by-Side	Access		
Quarry	Congress Development Co.	+ [2]	+	+	+		+					+	6	7.0
	Niagara Waste Systems	+	+	+	+		+				+		6	
	Glenridge Quarry	+	+	+	+		+		+			+	7	
	Fred Weber, Inc.	+	+	+	+	+	+		+		+	+	9	
Metaliferous	Eagle Mountain Landfill	+	+	+			+ [3]	+		+		+	7	7.0
Non-indurated Material	Parklands Reclamation		+	+	+	+	+						5	4.0
	Blackwell Forest Preserve					+			+		+		3	
Coal	West Side Sanitary Landfill		+			+						+	3	4.4
	Gallatin National Balefill	+	+	+	+		+	+	+	+		+	9	
	Duquesne Light Landfill	+	+	+	+ [3]	+	+ [3]	+	+				8	
	Linn County Landfill					+							1	
	North Mountain Landfill					+							1	

[1] Descriptions of each judgment criterion are given in the text

[2] A "+" indicates a passing grade for a judgment criterion.

[3] Conditions are such that this system is not needed.

Table 1: Evaluation of the Success of Landfills.

Table 1 also shows the total number of passing grades that each landfill site received. The highest score attained was nine out of a possible eleven, and the lowest score attained was one, with zero being the absolute minimum. Sites that received scores of 3.0 or less caused some level of groundwater contamination and are considered unsuccessful landfill projects.

Comparison by Mine Type

The average score for each different mine type is given in Table 1. The quarry sites and the metalliferous open pit mine tied for the highest average score of 7.0. This indicates the high individual rate of success of the landfill sites in these categories. The non-indurated material mines and the surface coal mines received average scores of 4.0 and 4.4 respectively. Although these types of mines received low average scores, they may still be considered suitable for solid waste disposal because the scores were greater than 3.0, the minimum score at which some level of groundwater contamination occurred. Overall, these average scores indicate that it may not be appropriate to determine the suitability of a mining area for solid waste disposal by mine type. In both the surface coal mines and the non-indurated material mines, there were individual sites that were successful.

Comparison by Common Characteristics

It may be more appropriate to evaluate the case study sites individually, rather than in groups and to compare the successful and unsuccessful sites for common characteristics. The best landfill sites provided the highest level of environmental protection through the use of groundwater flow control devices, competent liners, and good leachate management techniques. Site selection and advanced planning are also important factors.

Conversely, the unsuccessful landfill sites failed due to poor site selection, poor designs, and improper landfill construction and operation procedures. Three of the four failed sites were constructed prior to the institution of present federal legislation and when an understanding of leachate production and leachate transport was limited. Although the design was fairly modern at the fourth failed site, this site was unsuccessful due to improper waste disposal practices.

Conclusions

From the analysis of twelve landfill sites, it was determined that, under the proper conditions, modern landfill design techniques make it possible to locate a solid waste landfill in a formerly mined area with no increased risk of environmental contamination. Landfills have been successfully constructed in limestone quarries, surface coal mines, an open pit iron ore mine, and in a clay pit. To be successful, it is important that the landfill is sited in an area with characteristics suitable for solid waste disposal, including groundwater discharge zones with unfractured bedrock or low soil permeability. The operators should also take advance of on-site soils for utilization as landfill liners and/or daily cover materials.

Where landfills located in mining areas have led to groundwater and surface water contamination, most of the failures can be attributed to factors other than that the landfill was located in a mine. In some cases, the landfill was operated improperly or the landfill design was not followed during construction. In other cases, the site selection was poor and environmental contamination would have occurred even if the site had not been mined. The fact that an area has been previously mined does not eliminate it from consideration as a solid waste disposal site. When properly designed and operated, there are many advantages to siting a landfill in a mined area. Landfill construction should therefore be considered as a viable reclamation method for mine sites. The benefits to both operations can be further increase when mining and waste disposal are carried out contemporaneously. Considering the shortage of acceptable landfill sites and the difficulty of the landfill permitting process, all potential landfill sites, including formerly mined areas, should be given due consideration.

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