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Landfill Management and Remediation Practices in New Jersey, United States

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1. Introduction

In 2009, the United States generated 243 million tons of municipal solid waste equaling 1.97 kg per person per day. Approximately 54% or 131.9 million tons of municipal solid waste was landfilled, with a similar percentage in 2008 and 2007, which is equivalent to a net per capita landfilling rate of 1.07 kg per person per day. Municipal solid waste includes commercial waste but does not include industrial, hazardous, or construction waste (US EPA, 2010). Therefore, approximately 7.6 million additional tons of industrial wastes are disposed of in landfills in the United States each year (EPA, 2011a). In 2003, New Jersey (a state located in the Northeast of the United States) alone generated 19.8 million tons of solid waste, with 9.5 million tons sent for disposal (NJDEP, 2006).

Landfills are the ultimate disposal of waste after recovery (i.e. recycling and reuse) and combustion, and the most acceptable and used form of solid waste disposal in the United States and throughout the world due to low costs in terms of exploitation and capital costs (Renou et al, 2008). However, municipal, commercial, industrial, hazardous, and construction materials contain nonhazardous and hazardous waste such as cleaning fluids and pesticides. Hazardous waste is harmful to the health of humans and the environment, exhibiting one of the following characteristics: toxicity, reactivity, ignitability, or corrosivity (EPA, 2011b). Non-hazardous waste includes all materials thrown in the garbage, sludge from wastewater, water, and air treatment plants, and wastes discarded from industrial, commercial, community, mining, and agricultural activities (EPA, 2011a). In the early 20th century, nonhazardous and hazardous wastes were regularly burned (Hansen & Caponi, 2009) and/or placed in unlined landfills coming into direct contact and polluting the air, water, and surrounding land (Duffy, 2008). To remedy the pollution caused by landfilling, appropriate remediation options should be performed. The most common methods for the remediation of landfills include excavation to recover recyclable materials, capping to reduce leachate generation, air sparging and soil vapor extraction to capture and remediate gases, and pump-and-treat of the leachate-contaminated plume. In contrast, modern landfills minimize the amount of landfill contamination cause through liner systems, leachate collection, and caps. The government controls landfills to ensure that they are properly operated, maintained, designed, closed, and monitored (Environmental Industry Association, 2011).

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As the human population, along with the industrial, municipal, and commercial sectors, continues to grow exponentially, the amount of waste generated will significantly increase over the years (Renou et al, 2008). The number of municipal landfills and amount of waste landfilled have declined combined with an increase in recycling and composting rates over the past 40 years in the United States (EPA, 2010). However, the majority of waste is already located in landfills (Environmental Industry Association, 2011) and landfills are still the most common form of waste disposal in the United States (EPA, 2010). As of 2003, approximately 21.3 years of landfill capacity remained in the United States, and less than ten years of capacity left in New Jersey (Hansen & Caponi, 2009).

2. Background

2.1 Environmental impacts

2.1.1 Impacts of Landfills on water, land, and air

Environmental impacts from landfills, principally caused by leachate generation and gas production, include air emissions, climate change, groundwater pollution by leachate, and relevant nuisance issues (i.e. odor, litter, vectors, and dust) (Hanson & Caponi, 2009).

When landfills consisted mainly of excavated pits, the waste would come directly into contact with and contaminate the surrounding surface and groundwater. During a precipitation event, water percolates through the landfill system creating leachate, which is highly contaminated wastewater. The composition of leachate can be categorized into four main groups: dissolved organic matters (mainly volatile fatty acids or humic-like substances); inorganic macrocomponents such as calcium, magnesium, sodium, potassium, ammonium, iron, magnesium, chloride, sulfate, and hydrogen carbonate; heavy metals like cadmium, chromium, copper, lead, nickel, and zinc; and xenobiotic organic compounds such as chlorinated organics, phenols, and pesticides (Kjeldsen et al, 2002; Renou et al, 2008). The surface runoff creates gullies and erosion, washing debris, contaminants, and sediment into nearby surface water bodies (Duffy, 2008). Landfill leachate harms surface water bodies by depleting dissolved oxygen (DO) and increasing ammonia levels altering the flora and fauna of the water body (Kjeldsen et al, 2002).

Air pollution is caused via two routes, the open burning of garbage and the anaerobic degradation of the organic fraction in solid waste. The open burning of garbage creates smoke, polluting the air and producing open debris. The natural, anaerobic decomposition by microorganisms transforms the waste organic fraction into methane and carbon dioxide, which are two primary greenhouse gases (Hanson & Caponi, 2009) and may kill the surrounding vegetation. The decomposition rate and amount of gas production depend heavily on the temperature and precipitation of the area (Duffy, 2008). Methane is a potent greenhouse gas that is 23 more time potent than carbon dioxide. Even though landfills are not the leading source of greenhouse gas production, they are the primary contributor to anthropogenically produced methane. (Hanson & Caponi, 2009) Volatile organic compounds (VOCs) are also released into the air directly from the products themselves such as cleaning fluids (NSWMA, n.d).

The produced gas and generated leachate from landfills must be properly collected and treated before they move offsite and further affect environmental and human health (NSWMA, n.d.) Of note, the leachate generated from the landfill bridges solid waste with

the hydrosphere (particularly groundwater) and lithosphere (i.e. soil), while the landfill gases connect solid wastes to the atmosphere. Therefore, it is vital to understand that landfill engineered sites have a potential to pollute more than one of the Earth's spheres.

2.1.2 Decomposition of solid waste in landfills

Typically, solid waste within landfills undergoes four stages of decomposition: an initial aerobic phase, an anaerobic acid phase, an initial methanogenic phase, and a stable methanogenic phase. The initial aerobic phase lasts only the first couple of days as oxygen in the voids is quickly depleted without any replenishment when the waste is covered. Therefore, an aerobic biodegradation of organic fraction of solid waste solely occur during a very short period, in which carbon dioxide is produced as a product and the temperature of the waste is increased. Leachate produced during this phase comes from direct precipitation or released from the moisture content of the waste itself (Kjeldsen et al, 2002). With the depletion of oxygen, the landfills quickly become anaerobic, and aerobic microbes dominate within the landfills, allowing fermentation to take place. Therefore, in the following anaerobic acid phase, the complex organic molecules are mostly degraded to volatile fatty acids, leading to a pH decrease. The initial methanogenic phase begins when methanogenic microorganisms grow in the waste, further transforming the volatile fatty acids to methane and carbon dioxide (Renou et al, 2008). The consumption of the organic acids raises the pH of the waste. During the stable methanogenic phase, the pH continues to increase. Methane production peaks and then declines as the amount of soluble materials decreases. The remaining waste is mainly refractory, non-biodegradable compounds like humic-like substances. The overall decomposition rates can be accelerated by a high moisture content and an initial aeration of the waste (Kjeldsen et al, 2002).

During different organic waste decomposition phases, landfill leachate and landfill gases may exhibit different characteristics. When volatile organic compounds dominate in the acid phase, leachate pH is typically at 3.0-4.0, under which heavy metals, such as calcium, magnesium, iron, and manganese, largely exist in leachate. Meanwhile, a huge number of biodegradable organic compounds are present in leachate, and 5-day biochemical oxygen demand (BOD₅) and chemical oxygen demand (COD) may reach a few tens of thousands of mg/L. And the organics are highly biodegradable characterized by a high BOD₅/COD (typically > 0.6). However, with the further decomposition into methanogenic phase and subsequent reduction in the concentration of organic acids, the leachate pH is raised to a neutral range, and the leachate organic content is significantly reduced. COD may drop to a few hundreds or thousands of mg/L, and the organic compounds are refractory with a low BOD₅/COD (typically < 0.3). And the concentrations of heavy metals in leachate greatly decrease as a result of precipitation more readily occurring at a high pH. When the landfill condition transform from aerobic to anaerobic condition, sulfate may be microbiologically reduced to hydrogen sulfide, so that the sulfate level is decreased with the landfilling time. Chloride, sodium, and potassium do not show a significant change in their concentrations throughout the decomposition, thus exhibiting an inert behavior. Ammonia-nitrogen concentrations remain high during all phases of decomposition, and thought to be the largest issue in landfill management for the long term. In leachate, monoaromatic hydrocarbons (e.g., benzene, toluene, ethylbenzene, and xylenes) and halogenated hydrocarbons are the most common xenobiotic organic compounds found. They are relatively recalcitrant. The concentrations of xenobiotic organic compounds vary broadly

depending on the landfill, with respect to age and restrictions of dumping hazardous waste (Kjeldsen et al, 2002). Recently, some emerging leachate contaminants, such as perfluorinated chemicals, pharmaceuticals, and engineered nanomaterials, at trace levels have been paid special attention to. However, their fates in leachate are poorly understood. For landfill gases, oxygen and nitrogen gases predominate in the initial phase because they, trapped from air, are buried together with solid waste, reflecting the composition of air. However, carbon dioxide and methane will gradually take over as products of anaerobic degradation of organic wastes. VOCs and ammonia may be present in landfill gases. Particularly, ammonia-nitrogen exists in forms of ammonium ions and dissolved ammonia gas in leachate. During methanogenic phases, leachate pH is back to neutral and even basic, and the fraction of dissolved ammonia will be increased. Therefore, the content of ammonia in landfill gases will be relatively high at these phases, and it can be quantitatively analyzed using the Henry's law that governs the distribution of dissolved ammonia gas in leachate and ammonia gas in landfill gases.

2.2 Landfill designs

Almost everything humans do creates wastes. However, waste did not become a problem until humans left the nomadic lifestyle and starting living in communities. As the world population has increase and changed from a rural agrarian society to a urban industrial society, the disposal of waste has become more concentrated. Dumping trash in the middle of cities was common practice in the United States until scientists linked human health problems to sanitary conditions in the early 1800's. In the early 20th century North America, cities began to collect garbage and either incinerated it at a landfill or home, or placed it in an unlined landfill (NSWMA, n.d.; Duffy, 2008). One of the first landfills was created in California in 1935, which consisted of a hole in the ground occasionally covered with soil (NSWMA, n.d.). Dumps were usually small and scattered affecting many areas (Duffy, 2008). Approximately 85% of U.S. sanitary landfills are unlined (Pipkin et al, 2010) and many are not covered, coming into direct contact with and polluting the air, groundwater and soil. Open dump burning was a common practice to reduce the volume of waste and increase the remaining capacity. When a landfill was closed, soil of varying thickness and slopes were placed over the waste (Duffy, 2008).

After the passage of laws and regulations that banned open burning at dumps, waste was spread into layers and regularly compacted to reduce the total volume, increase stability, and extend the life of the landfill. Modern landfills are located, operated, designed, closed, and monitored to ensure that the environment is appropriately protected (Environmental Industry Association, 2011). Newer landfills are restricted from being built in floodplains, wetlands, fault zones, and seismic impact zones unless the landfills have structural integrity and protective measures in place to protect human and environmental health. Protective operational procedures include rejecting hazardous and bulk materials, non-containerized liquids, the restriction of open burning, securing site access, and keeping up-to-date records on groundwater, surface water, and air monitoring results. Landfills are now designed with leachate collection and liner systems to prevent the migration of leachate off-site. A liner of low permeability materials such as clay, geotextiles, or plastic, with a leachate collection and recovery system placed on top of the liner. The leachate collected are either treated on or off-site at a wastewater treatment plant, while the gases produced are burned or converted into energy (i.e. electricity, heat, steam, replacement of natural gas, or vehicle fuel). Waste is

layered above the leachate collection system, compacted, and covered daily to reduce odors, vectors, fires, and blowing litter. When the landfill reaches a permitted capacity and then is closed, a final cap is placed on the top of the landfill to prevent precipitation seeping through the waste. The final cap consists of a low permeability material such as clay or synthetic material (NSWMA, n.d.). Storm water channels are constructed on and around the landfill to direct rainwater to retention ponds for erosion control and reduce surface water contamination. Lastly, a long-term monitoring plan is implemented to ensure the liner and gas/leachate collection systems are operating properly, and the surrounding or underlying groundwater is not contaminated (Environmental Industry Association, 2011). Properly designed landfills can be inexpensive means of disposal (Hanson & Caponi, 2009), but many landfills are older, poorly designed and not managed, thus causing numerous environmental impacts (NJDEP, 2006).

3. Regulations

The Solid Waste Disposal Act of 1965 was the first regulation on waste disposal in the United States, and formed the national office of solid waste. Within the following 10 years, every state had regulations on the management of solid waste, varying from the banning of open burning to requiring permits and regulations on design and operational standards (NSWMA, n.d.).

The Resource Conservation and Recovery Act (RCRA), passed by Congress in 1976, and the RCRA Hazardous and Solid Waste Amendments in 1984 granted the US Environmental Protection Agency regulatory control over the disposal of waste (Hanson & Caponi, 2009). The program was implemented to assess the problems associated with an increasing amount of municipal and industrial wastes that the nation was confronted with. RCRA separated hazardous and non-hazardous waste and mandated the Environmental Protection Agency to create design, operational, locational, environmental monitoring standards, to close or upgrade existing landfills, and secure funding for long-term assessment of the landfill (NSWMA, n.d.).

The solid waste program, under Subtitle D, requires states to create management plans, set criteria for solid waste, and restrict the use of open dumping. Subtitle D's regulations lead to the creation of larger, regional landfills and waste management companies, which improves environmental and economical integrity relative to the small, scattered dumps of the past. Larger waste management facilities are more cost effective in terms of capacity, volume, and operational resources (i.e. staff and equipment) to meet the increasing volume of waste (Duffy, 2008).

The Resource Conservation and Recovery Act addresses only active and future landfill sites, while the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), otherwise known as Superfund, focuses on abandoned or historical sites (EPA, 2011). The Environmental Protection Agency, through the Superfund program, holds the parties responsible for clean up or if no responsible party can be identified, the Agency uses money from a special trust fund. This program is a complex, long-term cleanup process involving assessment, placement on the National Priorities List (NPL), and implementation of appropriate cleanup plans (EPA, 2011). The National Priority List is a list of the sites

contaminated by hazardous waste and pollutants in the United States, eligible for long-term remedial action financed under the federal Superfund program, and guides the Environmental Protection Agency to which sites need further environmental assessments (EPA, 2011).

4. New Jersey landfills

Although the area of New Jersey ranks No. 47 in the 50 states of the United States, New Jersey is the most densely populated (462/km²) with a population of approximately 8.4 million residents. This state is faced with an increasing trend in volume of waste generation, combined with a declining trend in recycling rates, and a scarcity of open spaces to site new landfills. Compounding the problem is the large quantity of legal uncertainty regarding the permissible regulation of solid waste collection and disposal, and a marketplace that makes identifying additional disposal capacity difficult (NJDEP, 2006).

For the past thirty years, the Solid Waste Management Act has guided New Jersey in terms of the collection, transportation, and disposal of solid waste. The development of facility siting and recycling plans are the responsibility of twenty-one counties and the New Jersey Meadowlands District, and each municipality ensures the collection and disposal of solid waste adhere to the county plan (NJDEP, 2006).

In 2006, the Statewide Solid Waste Management Plan was updated from the 1993 version. Since 1993, New Jersey has undergone significant changes in terms of solid waste management including declining recycling rates, the loss of a variety of funding sources due to numerous taxes, invalidation of waste flow rules by the Federal Court, the partial deregulation of solid waste utility industry, and the state adopted the federal hazardous waste program. Two Federal Court decisions, "Atlantic Coast" and "Carbone", left many once financially secure disposal facilities with significant debt. After "Atlantic Coast" and deregulation of state control on regulatory flow, several counties controlled their waste and initiated an intra-state flow plans allowing waste to leave the state, but if the waste remains in New Jersey, it is sent to a facility in that county. Due to these changes, the resources needed to plan and execute an environmentally protective solid waste management program are not available (NJDEP, 2006).

In the mid 1970's, as old dumps were being closed and the generation of waste increased, the formation of environmentally friendly landfills could not maintain the increased waste, resulting in New Jersey becoming a net exporter of waste to neighboring states. Therefore, the state embarked on a mission to increase recycling rates while creating environmentally sound landfills for the remainder of the waste (NJDEP, 2006).

Some counties choose to create facilities using funds from revenue bonds backed by the guaranteed flow of waste to the publicly owned facility. By 1990, thirteen new facilities were built creating billions of dollars of public debt. However, a Federal Court ruling in "Atlantic Coast" invalidated this waste flow system. The public funded facilities could not modify their systems as easily as the counties that contracted with private entities and still pay for the acquired debt. These facilities have higher rates due to several aspects: the scarcity of

open spaces in such a densely populated state, having to accept even the unprofitable segment of the waste, the numerous taxes and surcharges supporting recycling programs, and the need for the proper closure of landfills in the future. In certain counties, the state decided to subsidize the debt payments and cleared certain loans related to solid waste management (NJDEP, 2006).

4.1 County plans

The Statewide Waste Management Act amended in 1975 mandated districts to establish solid waste management systems with emphasis on resource recovery such as recycling, composting, and incineration to minimize the disposal of waste in landfills. In the beginning of the 1980's, New Jersey Department of Environmental Protection (NJDEP) permitted the solid waste management plans for the 22 solid waste management districts, which include the 21 counties in New Jersey and the New Jersey Meadowland Commission. Currently, New Jersey contains 16 operating landfills, five of which have resource recovery facilities (NJDEP, 2006).

+The districts/ counties use four waste management systems, including non-discriminatory bidding flow control, intrastate flow control, market participant, and free market controls. The non-discriminatory bidding flow control is brought about due to the non-discriminatory bidding process, opening the bidding of contracts to companies both in-state and out-of-state for the disposal of a county's waste. The intrastate flow control system requires that all waste should be disposed of within the same county as it was generated, unless transported out-of-state for disposal. In a market participant system, a county owned facility is permitted to compete with in and out- of- state disposal facilities, and the free market system permits the ability to make freely agreed upon terms between the district/county, transporter, and disposal facility. Eight districts have the non-discriminatory bidding flow control, while the other districts utilize either a market participant or free market approach for disposal of the solid waste generated within their borders. (NJDEP, 2006)

4.2 Waste generation

Figure 1 depicts the solid waste disposal trends in New Jersey from 1985 to 2003 including in state and out-of-state disposal statistics. These figures illustrate a steady rise in solid waste generation during this period. This increase may be attributed to a strong economic landscape in New Jersey or a population rise.

Figure 2 shows the amounts of solid waste exported to the various neighboring states from 1990 to 2003. The export rates steadily increase for Pennsylvania and Ohio and more recently Delaware. The figure clearly shows that Pennsylvania receives the majority of New Jersey waste if it is exported out-of-state (NJDEP, 2006).

In 2003, New Jersey generated more than 19.8 million tons of solid waste, with 9.5 million tons sent for disposal. Of the 9.5 million tons disposed, sixty percent of the waste was disposed at facilities, including recycling facilities, in New Jersey, while forty percent or 3.9 million tons were sent to out-of-state facilities. The amount of exported waste has been increasing over the years (NJDEP, 2006).

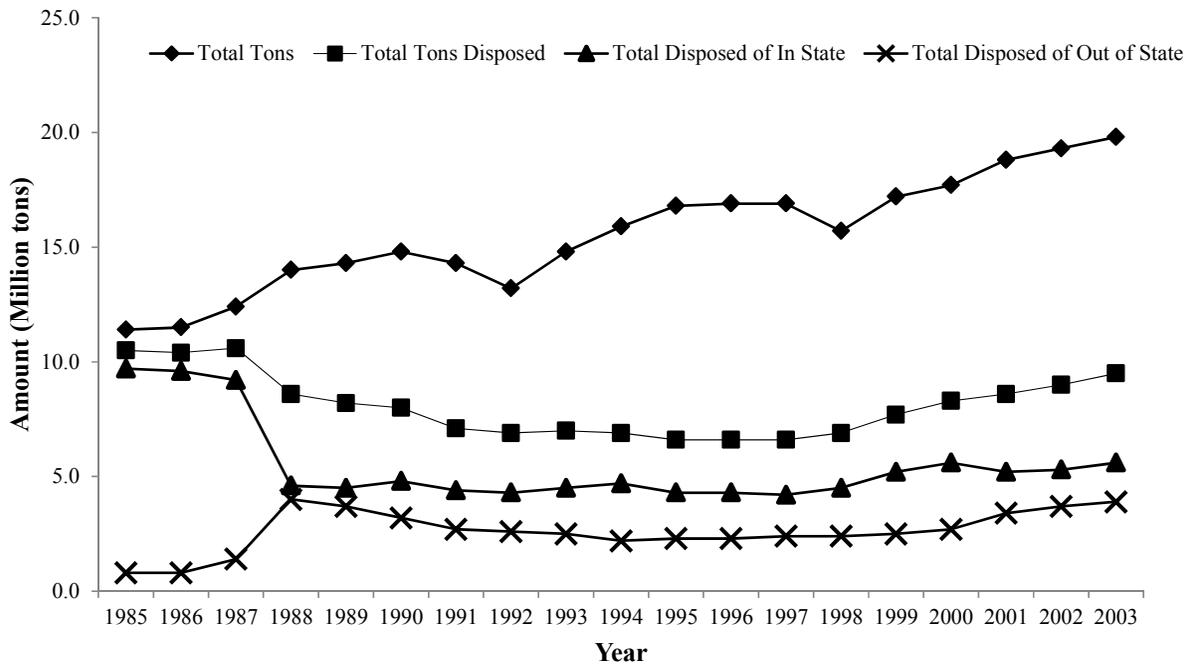
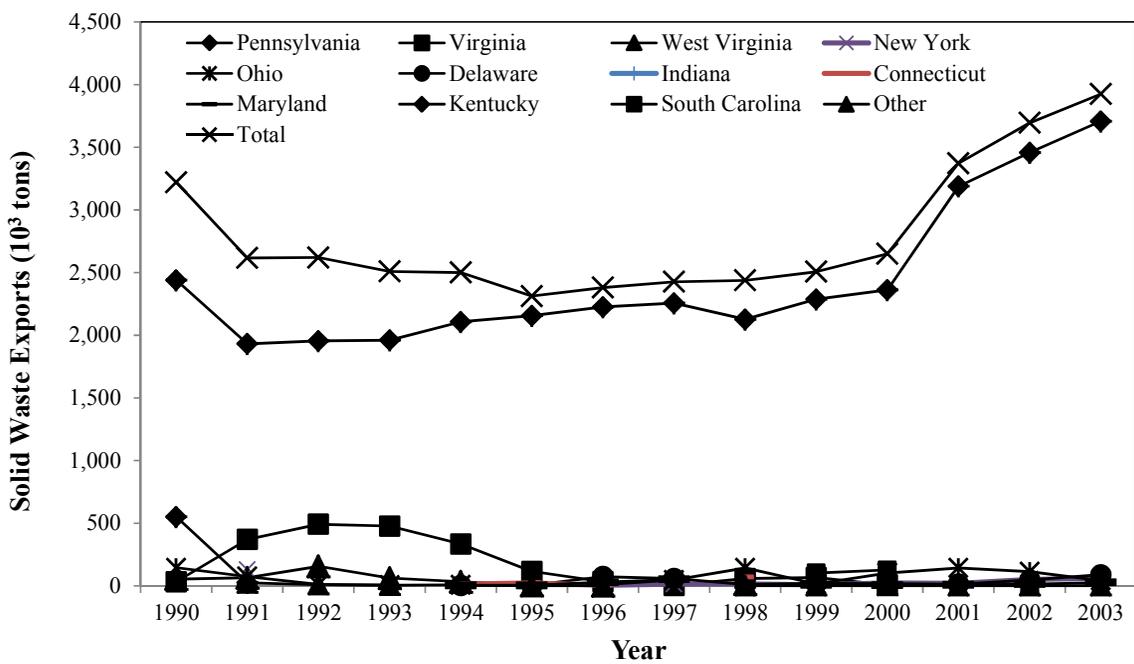


Fig. 1. New Jersey Solid Waste Trend Analysis (NJDEP, 2006)



*Note: Data for 1990 through 2003 was developed from information received from solid waste transfer stations and transporter monthly reports submitted to the New Jersey Department of Environmental Protection

Fig. 2. Solid Waste Exports from New Jersey to neighboring states (in 000's of tons) (NJDEP, 2006)

The New Jersey chapter of the Solid Waste Association of North America states that about 3.6 million cubic meters of waste was disposed of in 2004 and there is a sufficient permitted

capacity, 31.9 million cubic yards, remaining for the short term. This means that there is less than 10 years of landfill capacity left in New Jersey (NJDEP, 2006).

The “self sufficiency” policy of creating and preserving in state facilities that are environmentally protective and cost efficient for in-state generators has been limited by constitutional failures. Since new landfills in New Jersey are difficult to site and additional capacity at existing facilities are limited, this plan encourages activities for a sustainable landfill including leachate recirculation, use of alternative covers, and landfill mining. New Jersey will continue to identify and properly close all landfills, use public funds to remediate environmental problems, and promote brownfield redevelopment of closed landfills (NJDEP, 2006).

5. Analysis of contamination by NJ landfills

The contamination caused by active, inactive, and closed landfills in New Jersey, particularly landfill Superfund sites, is reviewed and analyzed. All the data on the landfills were acquired from US EPA, and then input into a database with regards to geographical location, contaminant type, pollution media, current status, and remediation method.

Since there were no regulatory requirements or mandatory registration for solid waste landfilling activities until the 1970s, many New Jersey landfills were poorly sited, designed, and controlled. In addition, solid waste from neighboring states was sent to New Jersey in an uncontrolled manner. The solid waste was dumped with little or no provision for cover to prevent odor, to control birds, insects, and rodents, or to minimize long-term environmental impacts. Even though New Jersey has the strictest design and performance standards for new landfills in the nation, there are many old landfills throughout New Jersey. The legacy of past landfills not designed with stringent controls for environmental protection or closed properly remains a significant challenge facing the state (NJDEP, 2006).

Most landfills established before to the mid- 1970’s lacked any leachate collection or control system, discharging the leachate directly to surface and groundwater causing serious water quality impairments. And closed landfills that do not have leachate collections systems require a costly retrofitting of a system to control discharges to surface and groundwater. Landfills, operated before the relevant environmental laws were enacted, accepted all types of waste, including industrial and commercial waste. Even after the laws were enacted, commercial and industrial waste continued to be illegally dumped at many municipal landfills. Therefore, many landfills may contain a variety of hazardous wastes. Nonetheless, municipal waste contains trace amounts of different household hazardous materials as homeowners dispose of paints, cleaning agents, solvents, and pesticides. As these hazardous materials accumulate in a landfill, a significant level of hazardous substances may result (NJDEP, 2006).

The largest anthropogenic source of methane gas emissions in New Jersey is landfills, accounting for 72% or 13.3 million tons of methane emissions. Approximately 35% or 1.9 million tons of methane emissions is released from only forty-seven landfills, both open and

closed. These sites should use energy recovery systems to capture and use the greenhouse gas as a renewable resource. Additional revenue is obtained when the methane gas is resold or used to generate electricity (NJDEP, 2006).

New Jersey implements energy recovery facilities at several large landfills. At one landfill, revenue is generated from the electricity sales and the carbon dioxide emission credits. All suitable landfills in New Jersey, both large and small, should develop these energy-to-recovery systems and assist in the funding to properly close the landfill and monitor gas emissions after closure (NJDEP, 2006).

In New Jersey, even if landfills do not receive wastes, they are not technically closed due to financial issues since final closure is expensive. All closure plans involve some degree of grading, landscaping, re-vegetation, site securing, drainage control, capping, and groundwater monitoring. Based upon historical experience in the solid and hazardous waste management program of the NJDEP, the following financial estimates are made. For a facility that requires the most limiting measures of closure may costs of up to \$180,000 per acre, while a more detailed closure involving an impermeable cap with a single synthetic geo-membrane could cost up to \$225,000 per acre. Finally, a full capping scenario of a remediation case, where substantial contamination has been identified and a 24-inch clay cap and synthetic membrane was used, the cost of closure increased up to \$ 700,000 per acre (NJDEP, 2006).

The NJDEP has more than 400 registered landfills and 200 additional sites suspected not to be registered. Before January 1, 1982, landfills were not required to submit detailed closure and post closure care plans. Therefore, out of the 400 registered landfills, 166 operated after 1982 submitting detailed plans under the "Sanitary Landfill Facility Closure and Contingency Fund Act" (Closure Act), N.J.S.A. 13:1E-100. The Closure Act places regulatory control upon closure and collects taxes on the landfills, which is reserved for final site plans (NJDEP, 2006).

Among the 146 NJ Superfund sites, namely NPL sites, 45 were, at least partially, contaminated by municipal and industrial landfill activities, of which only 10 have been completely remediated. The polluted media, in terms of occurrence frequency, are groundwater (91%), soil (62%), surface water (31%), wetlands (16%), and air (11%). A breakdown of the primary contaminated media for landfills on the Superfund list in New Jersey is shown in Figure 3. Moreover, 10s-100s of thousands of people reside within 5 km from these sites and they are located nearby natural water and public parks. Particularly, the Ringwood Mines Landfill is near a major drinking water source supplied for approximately 2 million people. Contamination of drinking water sources has been occurring but to date has been offset by improvements in detection and water treatment systems. Of the 45 NJ landfill Superfund sites, the most frequently found contaminants are volatile organic compounds such as benzene, contaminating 84% of the sites, and heavy metals like lead are found in 80% of the cases. Figure 4 shows the primary contaminants of landfills on the Superfund list in New Jersey.

Landfill leachate from the most landfills contain the common contaminants at different levels such as biochemical oxygen demand (BOD), chemical oxygen demand (COD),

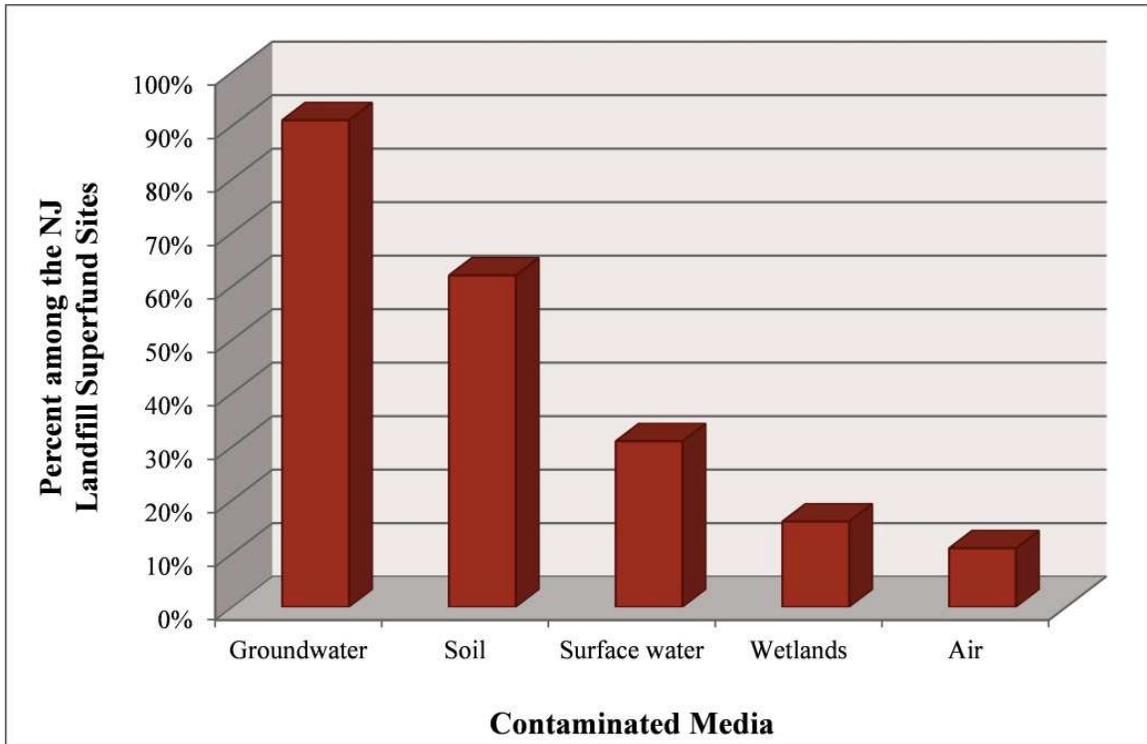


Fig. 3. Percentages of New Jersey landfill superfund sites in terms of different contaminated media

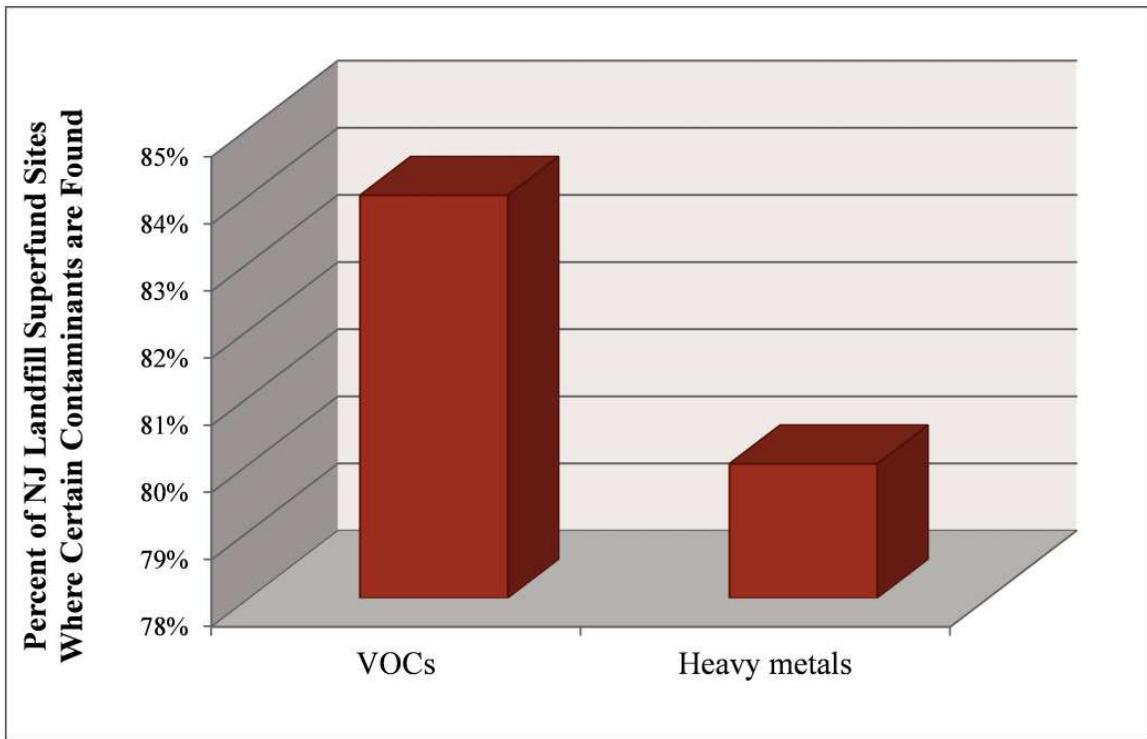


Fig. 4. Percentages of NJ landfill superfund sites where certain contaminants are found.

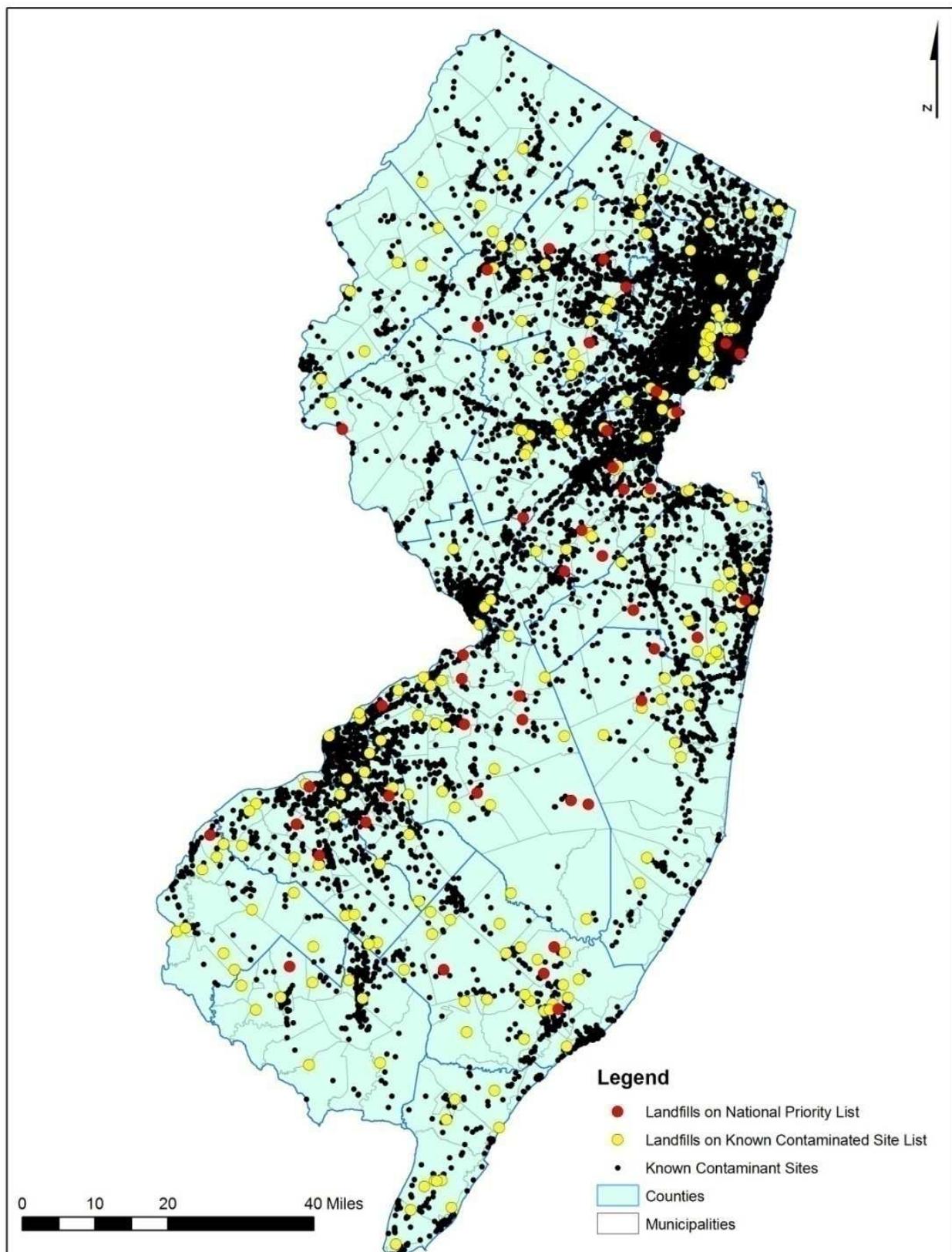


Fig. 5. New Jersey Landfills listed on the Known Contaminated Site List and the National Priority List

ammonia, heavy metals, and chlorinated hydrocarbons. However, due to old landfills accepting all types of waste and illegal dumping, the leachate from these landfills may contain uncommon pollutants (e.g. PCBs) derived from hazardous substances such as star, paint sludge, waste oils, drummed industrial waste, and medical waste. These old landfills with mixed solid wastes are usually the ones considered for redevelopment, which poses many problems with remediation (Wiley and Assadi, 2002).

New Jersey landfills listed on the Known Contaminated Site List and the National Priority List are shown in Figure 5. It would be noted that the known contaminated sites include all sites on the National Priorities List (Superfund sites) and other contaminated sites (e.g. brownfields). The majority of the landfills are concentrated the areas of New Jersey close to New York City and Philadelphia area, with a band connecting the two areas in central New Jersey. The counties with the most landfills are Atlantic, Middlesex, and Morris, with 9, 7, and 6 landfills, respectively, most likely as a result of high population density, urbanization, and industrialization.

6. Remediation methods

The frequently used remediation methods for landfills on the National Priority List in New Jersey include excavation to recover recyclable material, capping to reduce leachate generation, air sparging and soil vapor extraction to capture and remediate gases, and pump-and-treat the leachate plume .

Since siting new landfills is a lengthy, expensive endeavor and the community raises opposition to landfills nearby, New Jersey may not have suitable areas for a new landfill. Additionally, existing, operating landfills cannot adequately expand new cells. Therefore, the Statewide Waste Management Plan promotes the use of "sustainable landfills" implementing innovative technologies to extend the lifetime of the landfills. In addition to the methods mentioned above, New Jersey is researching alternative daily covers, deterring bulky wastes, landfill surcharging, and redevelopment opportunities (NJDEP, 2006).

6.1 Excavation/ landfill mining

Landfill mining consists of excavating and the subsequent processing of landfilled waste. This procedure recovers recycled materials, cover soil, and a combustible fraction to free landfill space. The excavation techniques for landfill mining have not changed since the 1950's and resembles surface mining. The excavated mass is processed through a series of screens for sorting. The amount recovered depends heavily on the physical and chemical properties of the waste, types of mining technologies used, and the efficiencies of the applied technologies

However, if the separated materials are contaminated or have a poor quality, the viability of recovering recyclable items from old landfills in New Jersey is reduced. Landfill mining would be most advantageous when the waste is fully decomposed and stabilized such as after either aerobic or anaerobic bioreactor (NJDEP, 2006).

6.2 Landfill caps

Capping a landfill involves three layers: an upper vegetative (topsoil) layer, a drainage layer, and a low permeability layer made of a synthetic material covering two feet of

compacted clay. Capping has a life span of about 50-100 years, but the performance of the cap depends on the site's environmental conditions. Cracking and erosion of caps can occur due to fluctuations in air temperatures and precipitation, and if the site is prone to subsidence and earthquakes. The cap must be adequately thick to prevent frost, and accommodate vegetative roots and burrowing animals (Vasudevan et al, 2003).

The use of temporary caps, instead of a final cap, on a filled landfill cell increases landfill space because the feet of soil typically used in a final cap is replaced with a synthetic membrane held down by removable items, like tires rather than soil. Temporary caps may be used in conjunction with leachate recirculation and active gas extraction. They are readily removable, and do not occupy much space like soil when the landfill is reopened for future landfilling activities. Some landfills are using temporary tarps to cover the waste instead of daily soil covers, increasing landfill capacity. Soil-like materials, like spray foam, can substitute soils as daily or intermediate cover material frees landfill space (NJDEP, 2006).

6.3 Landfill surcharging

When a landfill reaches final elevation levels, landfill surcharging may be implemented. The surcharging of a landfill involves the placement of a large amount of weight on top of the landfill for 6-12 months. The added weight to the top of the landfill causes enhanced settlement of the waste and increased capacity, which is recognized after the surcharge material is taken away. Clean soil is usually used as the surcharge material, which may be used elsewhere in the landfill after the surcharging process is completed (NJDEP, 2006).

6.4 Soil vapor extraction and air sparging

Soil vapor extraction (SVE) and air sparging are in-situ remediation techniques to remove vapors from polluted soil and plume, respectively (Vasudevan et al, 2003). Usually, SVE and air sparging are concurrently used in a site (EPA, 2001). Solvents, fuels (EPA, 2001), and volatile organic compounds (Vasudevan et al, 2003) are readily removed through these methods. Two types of wells are installed around the landfill, extraction wells and air injection wells. An extraction well creates a vacuum to draw the vapors to the surface, while an air injection well pumps air into the ground. The air injected stimulates the growth of aerobic microbes to enhance microbial decomposition. If the injected air is heated, the evaporation of the chemicals is accelerated.

SVE and air sparging are safe but may take years to reach full remediation depending on the size and depth of pollution, type of soil, and concentration of chemicals in the soil and groundwater. However, these methods are quicker than just relying on natural processes (EPA, 2001).

6.5 Co-treatment of landfill leachate with sewage in a wastewater treatment plant

Leachate management involves discharging to a wastewater treatment plant, pre-treatment before discharging to a wastewater treatment plant, or treatment onsite and following discharging to a nearby stream. The connection with a nearby sewer line is the most

common practice in the United States. Most of municipal wastewater treatment plants use aerobic biological treatment (e.g. activated sludge process), and were specially designed to aim at biodegradable organic matters and suspended solids in sewage. Therefore, refractory organics and emerging pollutants in leachate may be poorly removed. Although much large sewage, relative to leachate, can dilute the persistent pollutants from leachate, it should be noted that these leachate pollutants are not truly removed or eliminated. Moreover, toxic chemicals in leachate (e.g. ammonia and heavy metals) may disturb microbial activities and cause unusual operation in wastewater treatment plants. In addition, sewer lines may be unavailable, be of insufficient capacity, or be disallowed for some reasons for connection to nearby treatment plants. (Spengel and Dzombak, 1991).

6.5.1 Bioreactor landfills

The recirculation of leachate back into filled cells is an essential step in a bioreactor landfill, in which microbial activities are intentionally enhanced. The recirculation of leachate provide moisture and/or oxygen to stimulate the microbial degradation of solid wastes and simultaneously reduce the amount of leachate needed for treatment. A bioreactor landfill may be either aerobic or anaerobic, to reclaim landfill space. Aerobic bioreactor landfills inject both air and leachate into the waste, while anaerobic bioreactor landfills only inject leachate into the waste. The aerobic bioreactor increases microbial digestion rates, thereby resulting in quicker settlement of the waste compared to anaerobic bioreactor landfills. In contrast, anaerobic bioreactor landfills generate more methane gas. Thus, it is a promising candidates for energy recovery projects. However, the recirculation is not commonly accepted practice among the waste management community or is not favored by regulations (NJDEP, 2006).

6.6 Deterring bulky waste

Many landfills discourage the acceptance of bulky waste since bulky waste results in large voided spaces in a landfill due to the inert, or inability, to decompose in a landfill, which is an inefficient way to use a landfill especially when this material could be recycled. Bulky waste such as tree parts, construction and demolition debris, tires, carpets, are deterred from a landfill by implementing higher fees for this material or to build recycling and recovery facilities at the landfill to reduce the amount of material landfilled. Landfills can use crushed tires or construction and demolition debris for alternatives to covers or stone (NJDEP, 2006).

6.7 Brownfield redevelopment

Brownfield redevelopment remediates and preserves existing contaminated sites, like old landfills, for use in the future. Brownfield redevelopment provides economic development by establishing new areas for businesses and industry to expand, and gives people the opportunity to gather, visit, shop, recreate, or work in different places. Brownfield redevelopment not only provides economic advantages but also brings communities together in New Jersey. However, the redevelopment of landfills is a challenge due to a variety of contaminants involved and the geological issues of building above a landfill (Wiley and Assadi, 2002). The issues associated with landfill redevelopment projects include: the size of the landfill, contaminants' types, the size and depth of plume, type and

depth of waste, avoidance of open water areas, utilization of recyclable material for remediation and development, land value, finding a willing developer, regulatory guidelines, engineering designs, and financial incentives (NJDEP, 2006).

Depending on the end use for the site and landfill conditions, some sites may just need a traditional final cap and clean fill over the waste, while other sites may need to move and consolidate the waste into a more appropriate, controlled location. Some landfill redevelopments use residual materials such as contaminated sludge and recyclables to re-contour the site and surcharge the waste, which is cheaper than using several meter-deep clean fill soil. All brownfield redevelopment projects must acquire all needed permits by multiple layers of government; conduct remedial investigations of the degree of contamination, gas, and leachate contamination; investigate natural constraints such as wetlands and discharges into surface water; study public and environmental health and safety; and identify the stability and serviceability of the development structures (NJDEP, 2006).

The larger the site, the more the redevelopment project is going to cost due to the probability of more natural constraints and illegal dumping of hazardous waste, thus increasing the costs of remediation. The remedial cost per acre reaches a plateau at 130 acres or more (NJDEP, 2006). The NJDEP supports private developer's landfill closures and third party landfill closure projects. The 1996 Gormely Bill offers up to 75% in state tax credits for remediation costs, and other financial and legal incentives are provided under the 1998 Brownfield Law (NJDEP, 2006).

There are several examples of successful brownfield redevelopments projects in New Jersey. One of the largest redevelopment projects is the EnCap Golf Holdings, LLC, where several closed landfills were capped and remediated for the construction of a golf course, commercial development, and residential areas in Bergen County. Another example of a brownfield redevelopment of old landfills is the Borgata Casino on the Atlantic City Landfill (NJDEP, 2006).

7. Conclusion

In this study, the data review and analysis show that amount of municipal, industrial, and commercial waste are continuing to grow, continuously shrinking the remaining landfill space in New Jersey. Landfilling waste remains the best option for disposal, but New Jersey is a densely populated state without much capacity or areas to expand and create landfills. Even though landfill designs have improved significantly, many old landfills continue to pollute the air, groundwater, surface water, and soil. Cost benefit analysis followed by an appropriate cleanup strategy should be carefully implemented to clean up each contaminated site. While New Jersey implements innovative technologies to recover landfill space and remediate contaminated sites for redevelopment opportunities, most of these techniques continue to require many years of execution

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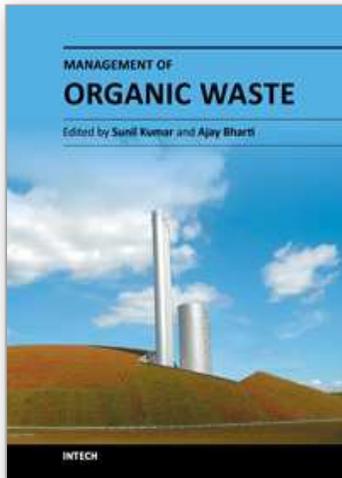
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This book reports research on the utilization of organic waste through composting and vermicomposting, biogas production, recovery of waste materials, and the chemistry involved in the processing of organic waste under various processing aspects. A few chapters on collection systems and disposal of wastes have also been included.

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