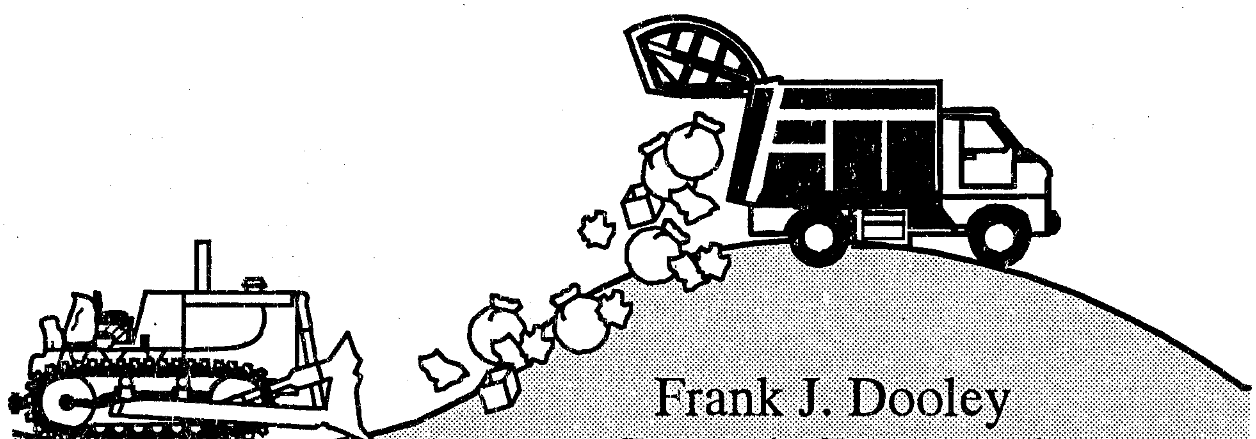
Agricultural Economics Report No. 294 March 1993

Estimating Optimal Landfill Sizes and Locations in North Dakota



Frank J. Dooley
Dean A. Bangsund
F. Larry Leistritz
William R. Fischer

Department of Agricultural Economics
Agricultural Experiment Station
North Dakota State University
Fargo, North Dakota 58105

Acknowledgments

The authors wish to acknowledge Martin Schock, Steven Tillotson, and Bob Wetsch, North Dakota State Department of Health and Consolidated Laboratories, for their help in providing information and editorial comments.

Thanks also are given to Rita Hamm and Charlene Lucken who edited the document and Jim Baltezore, David Givers, Mark Krause, and Jay Leitch who reviewed the document. Finally, thanks to Lucy Radke and Shelly Swandal who assisted in document preparation.

Financial support for the study was provided in part by the Environmental Protection Agency under contract with the North Dakota State Department of Health and Consolidated Laboratories.

The authors assume responsibility for any errors of omission, logic, or otherwise.

List of Tables

List of Figures

List of Appendix Tables

Table **Page**

Table of Appendix Tables (Continued)

Table **Page**

HIGHLIGHTS

Environmental interest groups have raised concerns about the disposal of municipal solid waste (MSW). In response, states have formulated solid waste disposal plans. Despite recycling programs and incineration, solid waste disposal plans still need to incorporate landfills.

The United States Environmental Protection Agency recently adopted stringent guidelines and restrictions for the construction, operation, maintenance, and closure of landfills. These regulations will increase the cost of operating landfills. Growing environmental resistance to using landfills has also caused other difficulties (e.g., finding acceptable locations, water contamination, transporting waste, funding contingency plans). To provide for disposal of MSW at acceptable costs, the North Dakota State Department of Health and Consolidated Laboratories has recommended a regional approach to solid waste disposal. The basic economic problem of regional MSW disposal is to recognize the tradeoffs between facility operation and transportation costs.

To approximate current landfill conditions and provide for model flexibility, landfill sites were selected for each county, with five counties having two possible sites. Five landfill size options were used, ranging from 20 tons per day (TPD) to 400 TPD. At four pounds per capita per day, North Dakota was estimated to generate about 466,325 tons of MSW annually.

A mixed integer programming model was used to minimize the cost of regional waste disposal. Model inputs included waste generation rates (developed from subcounty units called wastesheds), possible landfill sites, landfill size options, annualized fixed costs of building and maintaining landfills, variable operating costs, and transportation costs for MSW. Collection costs were not addressed in this study.

A baseline scenario, with a landfill built in each county, provides a benchmark for comparison. The annual total cost of disposal under the baseline scenario was $16.9 million, with an average total cost of $36.20 per ton. With an optimum size and location solution, annual disposal costs were $12.2 million, with an average total cost of $26.27 per ton. When waste disposal was regionalized, total and average costs declined by 27 percent. Ten regional landfills were built instead of 54 under the baseline scenario.

Under the optimal solution, 250-TPD regional landfills were built at Bismarck, Fargo, and Grand Forks; 175-TPD regional landfills were built at Dickinson, Jamestown, and Minot; and 75-TPD regional landfills were built at Devils Lake, Rolla, Wahpeton, and Williston. In addition to the 10 regional landfill facilities, Fort Berthold Native American Reservation and Standing Rock Native American Reservation each built a 20-TPD facility (tribal lands do not fall under the jurisdiction of the North Dakota state government).

The amount of waste generated in the state was reduced to reflect the potential statewide effect of future recycling programs. Using landfill locations and sizes in the optimal solution and 30 percent less waste statewide, total costs decreased 19 percent. However, average costs per ton increased 16 percent. When the model was rerun, landfill sizes decreased at Dickinson, Grand Forks, Jamestown, and Rolla, while a landfill facility *was not built at Wahpeton. Recycling could lead to overcapacity in landfill facilities, reducing overall costs of waste disposal and increasing the per ton cost of disposal.*

Transfer stations, small collection facilities used to congregate and transport waste more efficiently, were included in another regional scenario. Assembling waste through transfer stations reduced annual disposal costs $943,000 and average total cost per ton $2. Transfer stations expanded the draw area for Devils Lake and Jamestown, but decreased the size of landfills built at Rolla and Grand Forks. Transfer stations could lower annual MSW disposal costs.

Other scenarios, involving changes in local areas of the state were analyzed to determine the effect on size and location of regional landfills. Regional landfill locations and size options are sensitive to decisions made by local jurisdictions in North Dakota as well as surrounding states. If waste was imported from Minnesota, Gwinner would build a regional facility instead of Wahpeton. The decision to build a facility at Wahpeton was sensitive to decisions about building in Gwinner and Fargo. The decision to build a 75-TPD waste incinerator at Grafton will affect the size of landfill built at Grand Forks. If Fargo, Bismarck, and McKenzie County only handle their own MSW, additional landfills would be built at Rugby (20-TPD facility) and Wilton (75-TPD facility).

Almost two-thirds of the state's counties, those with sparse populations and removed from urban centers, would incur high waste disposal costs if they developed their own landfill (annual waste disposal costs in excess of $50 per ton are likely). However, under regionalization of waste disposal, these same counties enjoy the greatest savings. Regionalizing waste disposal could potentially save the state over $4 million per year, with most of the savings realized by remote, sparsely populated counties. Thus, a considerable economic incentive exists to adopt a regional waste disposal plan.

ESTIMATING OPTIMAL LANDFILL SIZES AND LOCATIONS IN NORTH DAKOTA

Frank J. Dooley, Dean A. Bangsund, F. Larry Leistritz, William R. Fischer*

INTRODUCTION

Managing municipal solid waste (MSW) is a growing problem in North Dakota and nationwide. Households, businesses, and industry generate municipal solid waste at a per capita rate of about four pounds per day (U.S. Environmental Protection Agency 1990b). The per capita rate of MSW generation is expected to continue increasing into the next century.

To cope with growing quantities of municipal solid waste, an integrated solid waste management hierarchy has been recommended. The hierarchy has four tiers: source reduction, recycling, incineration, and landfilling (U.S. Environmental Protection Agency 1989). *Source reduction* is changing resource use to reduce waste generation. *Recycling* includes separating and collecting recyclable materials and processing and returning those materials to the marketplace. *Incineration* of municipal solid waste involves burning garbage to reduce its volume and/or to recover energy for electric power generation. *Landfilling* will continue to be necessary even if the other three techniques are used effectively.

While additional landfill space is needed, mounting concern about protecting groundwater and other environmental resources has led to stringent regulations governing the design and operation of these facilities. Pursuant to the Resource Conservation and Recovery Act, regulations have been adopted for the operation (Subtitle C) and design (Subtitle D) of municipal solid waste landfills.[1] These regulations become effective October 1993. Among the most salient changes from previous requirements are those that mandate synthetic liners and leachate collection systems for most landfills (Walsh 1988). While these environmental protection devices are designed to prevent groundwater contamination by leachate, they make new landfills expensive relative to old designs. Thus, Subtitle D requirements will substantially increase the economies of size in landfill development and operation. That is, large capacity landfills will have cost advantages over smaller capacity landfills.

Existing landfills in most North Dakota communities will soon need to be replaced or upgraded to comply with Environmental Protection Agency (EPA) requirements. However, the requirements of Subtitle D will make small community-based landfills prohibitively expensive to develop and operate. To provide MSW management at acceptable costs, regions throughout the state are developing solid waste management plans. While a variety of factors must be considered in developing regional plans for

---

*Assistant professor, research associate, and professor, respectively, Department of Agricultural Economics, North Dakota State University, Fargo. Fischer is research associate, Center for Economic Development, University of Wisconsin-Superior.

[1]The regulations, which are found in 40 CFR § 258, were adopted as part of the Resource Conservation and Recovery Act (42 United States Code § 6944 (1984)).

MSW management, the basic economic problem is one of selecting optimum sites for and sizes of landfill facilities. Solutions to this problem must consider the regional pattern of MSW generation and the trade-off between facility operation costs and MSW transportation costs. Landfill costs are lower on a per ton basis for larger capacity facilities because of economies of size. MSW transportation costs increase when MSW must be transported greater distances to larger facilities. An additional factor in landfill site and size selection is the role of transfer stations.

PURPOSE

The purpose of this project was to estimate the number, location, and capacity of MSW landfill facilities that would minimize the total cost of waste transportation and disposal for North Dakota communities. To accomplish this, it was necessary to estimate:

1. the amount of waste generated annually in North Dakota,

2. the fixed costs of establishing and variable costs of operating landfills of different sizes, under Subtitle D constraints,

3. the operating costs of transfer stations, and

4. the cost of transporting solid waste from generation location to disposal facility.

Transportation and disposal costs did not include the collection phase of solid waste disposal (i.e., curbside pickup costs). This information was then used in a cost-minimizing, mixed integer programming model to find the optimum size and location of landfill facilities.

The model was used to estimate the disposal and transportation costs for the eight scenarios. In some cases, several options were run for a particular scenario.

Scenario A - One landfill in every county. This model provides a baseline. Two options are considered, one with all waste and the other with only half the waste from rural areas. The second option assumes that some rural residents continue to burn or dispose waste on their own.

Scenario B - Regional cost optimization. This model provides a regional solution to siting and sizing landfills.

Scenario C - Impact of recycling. The sites from Scenario B are fixed, but the model is re-estimated with 30 percent less waste to evaluate the effect of recycling programs.

Scenario D - Transfer stations. Sites not selected for landfills in Scenario B are sites for possible transfer stations. This model evaluates collecting trash at transfer stations and then reshipping by semitrailers to landfills.

Scenario E - the Grafton incinerator. The Grafton area is considering building a 75-ton per day incinerator. This will identify their assembly area and the effect on other landfills in the state.

Scenario F - Local options. Bismarck, Fargo-West Fargo, and McKenzie County are assumed to "go alone," building landfills for only their immediate area. This model considers the effect on landfill requirements for the rest of the state.

Scenario G - Exclude Ellendale. At the time the study was conducted, Ellendale shipped their waste to South Dakota. However, as of January 1993, Ellendale contracted to ship their waste to a site in North Dakota.

Scenario H - Combines Scenarios E, F, and G. In addition, landfills at Fargo, Grand Forks, and Gwinner are allowed to accept waste imports.

MUNICIPAL SOLID WASTE MANAGEMENT IN NORTH DAKOTA

The North Dakota State Department of Health and Consolidated Laboratories is the state agency responsible for developing solid waste management plans, enforcing environmental standards, and issuing permits for landfills. North Dakota had 50 permitted MSW landfills in 1991 (Figure 1). This represents a substantial decrease from 110 permitted landfills in 1987. Three reasons explain this decline. First, the North Dakota State Department of Health and Consolidated Laboratories has closed open dumps in hydrogeologically unsuitable areas. Second, some landfills have been voluntarily closed as others expanded to the role of regional facilities. Finally, some communities recognized that closing their landfills would be less costly than complying with the regulations.

LANDFILL REQUIREMENTS UNDER SUBTITLE D

The U.S. Environmental Protection Agency (1991) organized landfill requirements of Subtitle D into eight categories: location restrictions, design specifications, operating criteria, groundwater monitoring requirements, corrective action, closure criteria, postclosure care, and financial responsibility.

With some exceptions, location requirements restrict landfills from being constructed in six specific areas. They cannot be constructed within 10,000 feet of an airport runway. They must be built beyond the 100-year flood plain. Landfills are banned from wetlands, which are defined as any area that supports water and wildlife that require that water for habitat. Fault areas, seismic impact zones, and unstable areas cannot contain landfills.

Design requirements indicate the engineering standards that must be built into each landfill. Two design options are available to landfill designers, the site specific or the composite liner. The composite liner design was used in this study because of its universal acceptance (Figure 2). It contains two components. The upper component must be a 30-mil flexible membrane made of a plastic or other impermeable substance. The lower component must be a 2-foot layer of compacted soil with hydraulic conductivity of

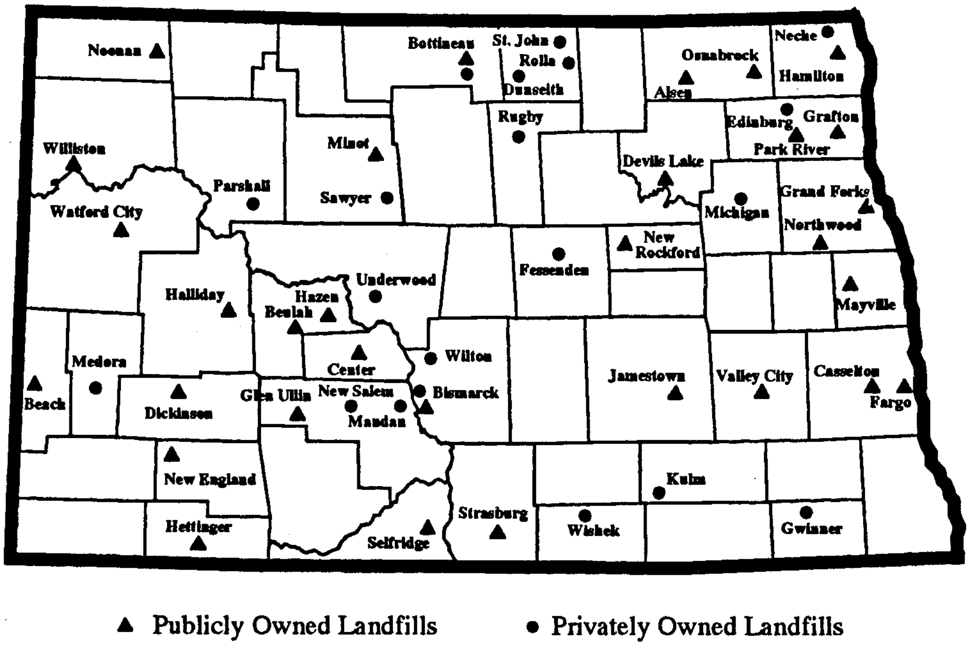


Figure 1. Permitted Landfills in North Dakota, 1991.
Source: Schock 1991.

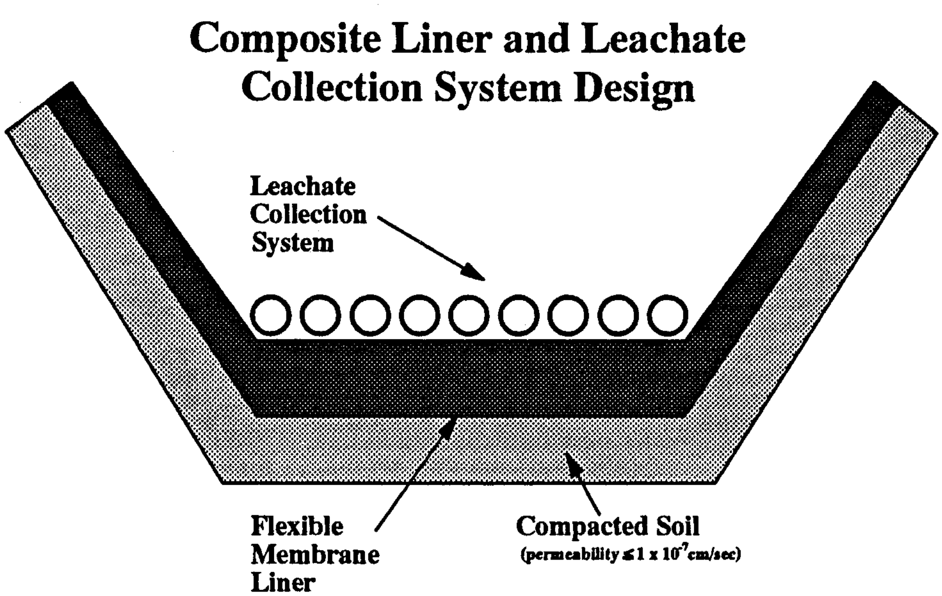


Figure 2. Composite Liner Design Criteria for Municipal Solid Waste Landfills.
Source: United States Environmental Protection Agency 1991.

not more than $1x10^{-7}$ centimeters per second. Other engineering standards are designed according to site specific conditions.

Landfill operators are required to follow certain criteria when receiving waste and keeping records. They must prevent the dumping of hazardous waste. A plan for detecting hazardous waste must be formulated and implemented. Six inches of earthen material must cover the waste at the end of each day's activities or more frequently if deemed necessary. Measures must be taken to control disease vectors and explosive gas accumulation. Landfill operators must comply with state laws governing air pollution as required by the federal Clean Air Act. Open burning at landfills is prohibited except in certain circumstances. The operators of a landfill must control run-on and prevent run-off of surface water. They must not accept liquid wastes, and access to the facility must be controlled to prevent unauthorized dumping. Records must be kept of inspections so audits can be performed.

The groundwater around landfills must be monitored to detect any contamination that may occur from leachate. To do this, appropriately located wells must be drilled near the facility perimeter. A separate monitoring system for each unit well must be used. Background concentrations of contaminants in the groundwater must be sampled and analyzed before wastes can be received.

A corrective action plan must be formulated and implemented in case groundwater contamination is detected. The plan must include procedures to correct the contamination and to compensate those who may suffer as a result.

When a landfill reaches design capacity, its useful life is said to have expired. Operators must then follow closure requirements to seal the landfill. A compacted layer, consisting of 18 inches of earthen material with a hydraulic conductivity not more than $1x10^{-15}$ centimeters per second, must cover the landfill. An erosion layer of six inches of earthen material that can sustain native plant growth must cover the compacted layer. These activities must begin within 30 days after waste receiving has stopped.

The landfill facility must be maintained for 30 years postclosure. The final cover integrity and effectiveness must be sustained to prevent any excess leachate from accumulating. Groundwater monitoring and methane gas control also must continue.

To ensure funding to carry out postclosure activities, a financial responsibility account must be set up at the onset of a landfill project. A cost estimate for a third party to conduct postclosure activities must be contained in the operating records of a landfill. Funds for postclosure activities must be set aside throughout its useful life.

ESTIMATES OF MODEL COEFFICIENTS

The mixed integer programming model requires coefficient estimates of (1) the amounts of MSW generated at different locations in North Dakota, (2) landfill establishment and operation costs, (3) transfer station operating costs, and (4) MSW transportation costs. Data sources and assumptions applicable to each of these topics are discussed here.

QUANTITIES OF MUNICIPAL SOLID WASTE GENERATED

The quantity of MSW generated in various North Dakota communities was estimated as the product of population and per capita waste generation. Population for 176 wastesheds was obtained from 1990 Census data (U.S. Bureau of the Census 1991). Some waste planners have adopted different waste generation rates for rural and urban populations. The estimate of 4 pounds of MSW per person per day was recommended by the North Dakota State Department of Health and Consolidated Laboratories (1992) for use in developing regional solid waste plans in the state. The rate of 4 pounds per person per day was used for both rural and urban populations. The total generation of MSW was about 1,300 tons per day (TPD) or 466,325 tons per year (TPY) based on the state's 1990 population of 638,800.

All waste generated in rural areas may not end up in landfills. Thus, the baseline solution (Scenario A) is solved both with the 4 pound per day rate and with a rate adjusted for rural collection. The adjustment assumes that rural waste could only be collected from half of the residents. Rural residents are defined as anyone living in rural areas (farms, ranches, or in towns with less than 75 persons). The total generation of MSW was about 1,100 TPD or 399,208 TPY under this assumption.

LANDFILL COST ESTIMATES

Landfill[2] capital and operating cost estimates were developed for five landfill sizes-- 20, 75, 175, 250, and 400 TPD. The cost estimates were synthesized from four prior economic-engineering studies. They are Minnesota Department of Natural Resources 1992 (15 TPD landfill); Halbach 1990 (75-TPD landfill); Sebesta 1989 (175-TPD landfill); and Joyce 1990 (250- and 400-TPD landfill). Buell et al. (1990) developed the relationship of costs among different sized landfills, which was used to validate the consistency of the cost estimates.

Landfill costs consist of two types of costs, fixed and variable. Fixed costs vary with landfill size. The fixed costs for a big landfill will be more than those for a small landfill because the big landfill requires more land, more excavation, a larger liner, etc. However, once a landfill is built, the fixed costs are constant over time (for any sized landfill). Variable costs are costs per ton cost. Variable costs per ton vary with landfill size. Larger landfills have lower variable costs because labor and equipment are used more efficiently. Variable costs per ton do not vary during operation.

Landfill costs are categorized into four stages: predevelopment, initial construction, annual operations, and closure and postclosure care (Joyce 1990). Location restrictions and design requirements affect predevelopment and initial construction costs. Operating criteria, groundwater monitoring requirements, corrective action, and financial responsibility all affect the annual operation and continued development cost stages. To

---

[2]The term 'landfill' as used in this report, refers to the site where MSW is buried. It does not necessarily refer to the actual hole in the ground where waste may be buried. A landfill site may actually contain several waste burial holes.

the extent possible, the assumptions of the prior studies were standardized to reflect the operation of landfills in North Dakota.

Land Requirements

Land requirements for landfills vary according to waste volume, in-place compacted density of garbage, and the excavation depth to which the waste is buried. The amount of waste to be buried at a landfill is a function of the amount of waste received daily, number of days waste is received per year, and number of years of operation. Land requirements vary directly with the amount of waste to be buried, not considering various garbage densities and/or burial depths. However, compacted density and landfill depth can have different effects on land requirements (Figure 3). For example, a landfill receiving 75 tons per day (TPD) could require about one acre per year if the burial depth was 17 feet and compacted density was 1200 pounds per cubic yard. However, the same landfill might require nearly four acres per year if burial depth was limited to five feet.

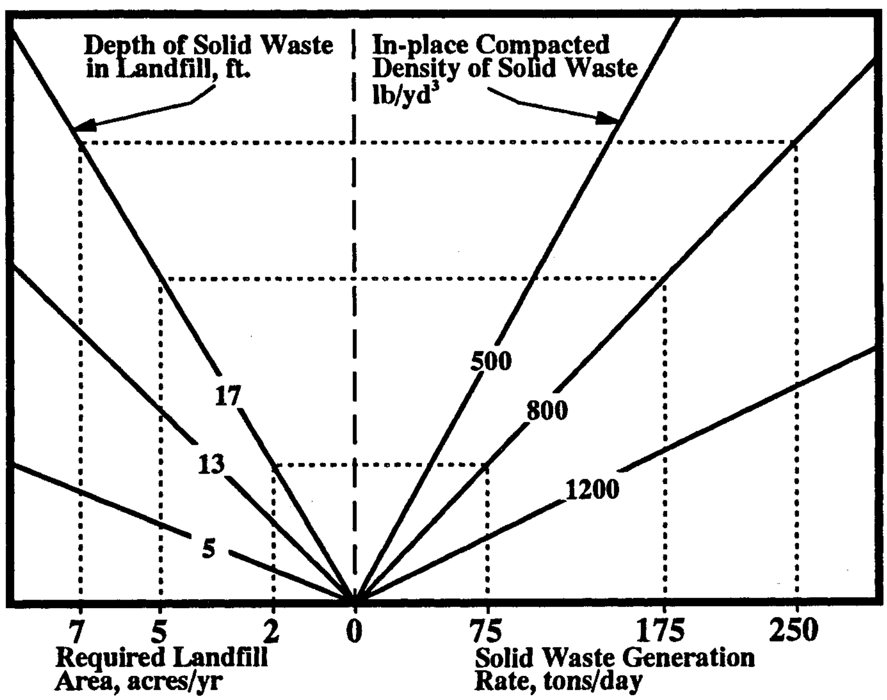


Figure 3. Acreage Requirements for Landfills Given Solid Waste Generation, In-place Compacted Density, and Depth of Landfill.
Source: Tchobanoglous et al. 1977.

Landfills in this study were assumed to operate with an in-place compacted garbage density of 800 pounds per cubic yard, have a 17-foot burial depth, receive waste 6 days a week, 52 weeks per year, and have a 20-year operating life. The number of acres required for landfills was estimated using the following formulas:

$$VOLUME/DAY = \frac{TPD * 2{,}000\ lb/ton}{compacted\ density\ (lb/yd^3)} \qquad (1)$$

$$FILL\ ACRES = \frac{VOLUME/DAY * 365\ days * 27\,ft^3/yd^3}{LANDFILL\ DEPTH\ (ft) * 43{,}560 ft^2/acre} \qquad (2)$$

In addition to land required for garbage burial, a buffer zone of 500 feet around a landfill perimeter was assumed. Buffer zones are needed to construct buildings and roads, and for groundwater monitoring wells. The wells must be about 500 feet from the landfill boundary on land owned by the project (U.S. Environmental Protection Agency 1991).

The total area needed to develop a landfill is the sum of the fill area and the buffer zone. The land requirements were 75, 132, 219, 283, and 398 acres for the 20-, 75-, 175-, 250-, and 400-TPD landfills, respectively (Table 1). Land prices were the average of 1990 to 1992 county cropland values adjusted for inflation (North Dakota Agricultural Statistics Service 1992, 1991, 1990; United States Bureau of Economic Analysis). The cost of land varied from $144 per acre in Sioux County to $884 per acre in Pembina County (Appendix A).

TABLE 1. LAND REQUIREMENTS FOR DIFFERENT SIZED LANDFILLS, NORTH DAKOTA, 1992

Land	Size of Landfill				
	20 TPD	75 TPD	175 TPD	250 TPD	400 TPD
	acres				
Buffer zone	60	87	118	138	168
Fill area[a]	15	45	100	145	230
TOTAL LAND	75	132	218	283	398

[a]Land requirements were based on an 800 pound per cubic yard compacted density, a 17-foot burial depth, and a 20-year life span. The fill area requirements were rounded up to the nearest five acres.

Predevelopment Costs

The predevelopment stage of a landfill project has four general cost categories. They are siting the landfill, engineering design, legal and public hearings, and other costs. Siting and legal hearings are fixed costs; since they do not vary regardless of landfill size. Siting the facility requires a hydrogeological study and a preliminary engineering investigation (Sebesta 1989). The site map, developed by engineers, contains the location of buildings, roads, and all other facilities (Joyce 1990). Siting the facility is assumed to cost $150,000, regardless of landfill size (Table 2). The costs for holding public hearings are fixed at $55,000 per landfill (Table 2).

TABLE 2. PREDEVELOPMENT COSTS FOR DIFFERENT SIZED LANDFILLS, NORTH DAKOTA, 1992

Item	Size of Landfill				
	20 TPD	75 TPD	175 TPD	250 TPD	400 TPD
Siting Landfill	$150,000	$150,000	$150,000	$150,000	$150,000
Design	80,250	141,240	234,330	302,810	425,860
Public Hearings	55,000	55,000	55,000	55,000	55,000
Administration	50,000	50,000	75,000	75,000	75,000
TOTAL COST	$335,250	$396,240	$514,330	$582,810	$705,860

Sources: Minnesota Department of Natural Resources 1992; Halbach 1990; Sebesta 1989; Joyce 1990; and Buell et al. 1990.

Engineering design costs and permitting expenses exhibit economies of size savings with larger facilities. Thus, the per unit cost is lower for larger landfills. The total fixed costs for design ranged from $80,250 for the 20 TPD to $425,860 for the 400-TPD landfill (Table 2). Administrative support costs are assumed to be $50,000 for the 20- and 75-TPD landfills and $75,000 for the larger sized landfills.

Construction Costs

The initial construction stage of landfill development includes roads, site excavation, liner development, construction of buildings and landscaping of grounds, erosion control grading, construction management costs, leachate control development, and final cover stockpiling. Erosion control is fixed cost at $80,000 per year for all sized landfills (Table 3). Construction management and buildings and grounds vary slightly by landfill size. The other costs vary with the size (in acres) of landfill.

Building costs did not vary much across landfill sizes because similar sized buildings are assumed. Building costs for the 20-TPD landfill are assumed to be $200,000, while they are $280,000 at the other landfills (Table 3). Erosion control costs are $80,000 across different sized landfills (Table 3). The construction management costs were assumed to be $100,000 for the 20- and 75-TPD landfills, rising to $125,000 for the larger sized landfills (Table 3).

Other fixed costs did vary with landfill size because of economies of scale in landfill construction. The cost of constructing access roads to the landfill and the working face (the portion of the landfill in current use) varies directly with the buffer area. The cost of roads is $900 per buffer acre for the 20- and 75-TPD landfills and $750 per buffer acre for

TABLE 3. CONSTRUCTION COSTS FOR DIFFERENT SIZED LANDFILLS, NORTH DAKOTA, 1992

Item	Size of Landfill				
	20 TPD	75 TPD	175 TPD	250 TPD	400 TPD
Building and Grounds	$200,000	$280,000	$280,000	$280,000	$280,000
Erosion Control Grading	80,000	80,000	80,000	80,000	80,000
Construction Management	100,000	100,000	125,000	125,000	125,000
Roads	54,000	78,300	89,250	103,500	126,000
Site Excavation	135,000	405,000	620,000	899,000	1,426,000
Liner Development	225,000	675,000	1,000,000	1,450,000	2,300,000
Leachate Control	55,500	166,500	240,000	348,000	552,000
Final Cover Stockpiling	17,250	51,750	115,000	166,750	264,500
TOTAL COST	$866,750	$1,836,550	$2,549,250	$3,452,250	$5,153,500

Sources: Minnesota Department of Natural Resources 1992; Halbach 1990; Sebesta 1989; Joyce 1990; and Buell et al. 1990.

the 175-, 250-, and 400-TPD landfill. Excavation, liner development, leachate control development, and final cover stockpiling vary directly with landfill fill area. The per fill acre costs are $9,000 for site excavation, $15,000 for liner development, $3,700 for leachate control development, and $1,150 for final cover stockpiling for the two smallest sized landfills. For the three largest sized landfills, the per fill acre costs are $6,200 for site excavation, $10,000 for liner development, $2,400 for leachate control development, and $1,150 for final cover stockpiling.

Total Fixed Costs Excluding Land Cost

Total development costs were predevelopment and construction costs plus 5 percent of these costs for unanticipated expense. Predevelopment and construction costs were amortized over the estimated useful life of landfills (20 years). An amortization rate of 7 percent was used to calculate the annual principal and interest cost. Since costs were realized evenly over the life of a landfill, the amortization rate did not have an effect on the distribution of costs over time.

Insurance and postclosure were not included as part of construction costs because they are realized on an annual basis rather than one time. The annual fixed cost of these two items is assumed to be $850 per rated ton of landfill capacity.

Fixed costs of establishing and operating a landfill vary greatly across the different sizes used. Assuming 100 percent utilization and a land price of $315 per acre, average fixed costs per ton decreased from $22.19 for a 20-TPD facility to $7.48 for a 400-TPD facility (Table 4). Recall that land costs were determined on a county basis to reflect differences in land values across the state. Thus, the fixed cost for the same sized landfill will vary with its location.

TABLE 4. TOTAL FIXED COSTS FOR DIFFERENT SIZED LANDFILLS, NORTH DAKOTA, 1992

Item	Size of Landfill				
	20 TPD	75 TPD	175 TPD	250 TPD	400 TPD
	Total fixed costs for development (lifetime costs)				
Predevelopment	358,875	437,820	583,315	671,955	831,230
Construction	866,750	1,836,550	2,549,250	3,452,250	5,153,500
Contingency	61,281	113,719	156,628	206,210	299,237
Total Development	1,286,906	2,388,089	3,289,193	4,330,415	6,283,967
	Fixed costs on a yearly basis				
Principal and Interest	121,475	225,419	310,477	408,761	593,162
Annual Fixed Costs	17,000	63,750	148,750	212,500	340,000
Total Fixed Cost	$138,475	$289,169	$459,227	$621,261	$933,162
Annual Capacity (tons per year)	6,240	23,400	54,600	78,000	124,800
Average Fixed Cost per Ton	$22.19	$12.36	$8.41	$7.96	$7.48

Sources: Minnesota Department of Natural Resources 1992; Halbach 1990; Sebesta 1989; Joyce 1990; and Buell et al. 1990.

Variable Operating Costs

Daily operation of a landfill requires expenditures on labor, equipment maintenance, utilities (electricity, fuel, water, and sewer services), leachate maintenance, and well monitoring (Table 5). Large savings are observed in labor, equipment maintenance, leachate maintenance, and well monitoring as landfills increase in size. Utilities expense is $0.46 per ton for all landfill sizes (Table 5). The operating cost of landfills varies inversely with size. The average variable cost ranges from $11.26 per ton at the 20-TPD landfill to $5.44 per ton at the 400-TPD landfill (Table 5).

TABLE 5. VARIABLE OPERATING COSTS FOR DIFFERENT SIZED LANDFILLS, NORTH DAKOTA, 1992

Item	Size of Landfill				
	20 TPD	75 TPD	175 TPD	250 TPD	400 TPD
	dollars per ton				
Labor	2.00	1.60	1.47	1.28	1.20
Equipment	2.80	2.40	1.83	1.60	1.50
Utilities	0.46	0.46	0.46	0.46	0.46
Leachate	5.00	4.26	2.29	2.25	2.00
Well Monitoring	1.00	0.73	0.45	0.33	0.28
Variable Cost per Ton	11.26	9.45	6.50	5.92	5.44

Sources: Minnesota Department of Natural Resources 1992; Halbach 1990; Sebesta 1989; Joyce 1990; and Buell et al. 1990.

TRANSPORTATION COSTS

Transportation costs were calculated for waste transfer in compaction trucks from generation site to landfill location. Distances were determined by routing trucks over the highway network. Previous studies estimated the cost per ton-mile (loaded cost per mile) to be $0.16 to $0.36 (Table 6). The higher cost estimate reflects higher labor costs in metropolitan areas. Assuming a running cost per mile of $2.00 and a 9.8 ton payload, the loaded cost per ton-mile used in this work is $0.20. This cost is assessed on a round-trip basis. For example, a generation site that is 20 miles from the landfill would have a transportation cost of $8.00 per ton ($.20/mile x 20 miles x 2).

Costs are much lower when MSW is hauled by semitrailers. Semitrailers were assumed to haul the trash from transfer stations to landfills. Compaction trucks were assumed to haul waste from wasteshed to landfill and from wasteshed to transfer station. Waste is more dense when shipped in semitrailers because waste is further compacted at

TABLE 6. TRANSPORTATION COSTS FOR HAULING MUNICIPAL SOLID WASTE IN COMPACTION TRUCKS AND SEMITRAILERS, NORTH DAKOTA, 1992

Item	Compaction Trucks			Semitrailers	
	Buell et al.	Fischer	Assumed	Buell et al.	Assumed
Cost per Running Mile	$4.40	$1.47	$2.00	$2.00	$2.00
Waste Density (lbs/yd)	700	700	700	1000	1000
Yards per Load	35	27	28	72	90
Tons per Load	12.25	9.45	9.8	36	45
Cost per Ton-mile (Loaded Cost/mi)	$0.36	$0.16	$0.20	$0.06	$0.04

Sources: Buell et al. 1990 and Fischer 1992.

transfer stations. Semitrailers also have a larger carrying capacity. The assumed cost per ton for semitrailers was $0.04 per ton-mile.

TRANSFER STATION OPERATING COSTS

Data on transfer station costs were not available. Thus, four cost options were modeled to test the model's sensitivity to transfer station costs. First, transfer station costs were assumed to be $8.00 per ton, with a capacity of 12 TPD. Second, the transfer station costs were assumed to be $12.00 per ton with the same capacity. Third, transfer station costs were $8.00 per ton, but the capacity was 18 TPD. Finally, transfer station costs were assumed to be $12.00 per ton with an 18-TPD capacity.

MODEL SPECIFICATION

A mixed integer programming model was used to select a cost-minimizing system of waste disposal in North Dakota in which the locations and sizes of landfills are selected. The objective function sums the costs of waste disposal and transportation (not including collection costs). Landfill costs were divided into the fixed costs of establishing a landfill and the variable costs of operating it. Transportation cost is the price of shipping one ton of waste from a generation point or transfer station to a landfill site.

The model was solved using LINDO, a mathematical programming software package. Mixed integer programming solves cost minimization problems using a branch and bounds technique. After obtaining an initial solution, LINDO changes the site or size of landfills one at a time and compares whether they increase or decrease costs. After all comparisons are made, it selects the solution with the lowest total cost as the optimal solution.

In general, the objective function form was

$$\text{Minimize Cost} = \sum_i \sum_j FC_{ij} IS_{ij} + \sum_i \sum_j VC_{ij} VS_{ij} + \sum_k \sum_j TC_{kj} GS_{kj} \qquad (3)$$

where:

Cost is the annual total cost of waste disposal in North Dakota.

The value of i denotes the different sized landfills possible at each site, i = 1, 2, 3, 4, 5.

The value of j identifies the different landfill sites, j = 1, 2, ... , 59.

The value of k denotes different wastesheds in North Dakota, k = 1, 2, ..., 176.

FC_{ij} is the annualized fixed cost of constructing and operating a landfill of size i at site j.

IS_{ij} is a binary integer variable that allows the annual fixed costs of a landfill of size i at site j to be added to total cost.

VC_{ij} is the variable cost per ton of operating a landfill of size i.

VS_{ij} is the number of tons transported to landfill size i at site j.

TC_{kj} is the cost of transporting one ton of waste from wasteshed k to landfill site j.

GS_{kj} is the annual number of tons of waste transported from wasteshed k to landfill site j.

Equation 3 is minimized subject to four constraints. The first constraint (Equation 4) requires that all waste generated annually in North Dakota be transported to a landfill. The value, $WASTE_k$, is the waste generated annually in wasteshed k. This constraint satisfies the study objective of disposing of all wastes in a timely manner. Ideally, the model would require all waste from a particular wasteshed to go to the same landfill. However, this restriction would prevent the model from generating a solution. While waste may go to more than one landfill, this will not be a widespread problem.

$$\sum_j GS_{kj} \geq WASTE_k, \quad \text{for all } k \qquad (4)$$

The second constraint (Equation 5) is a transfer row that transports waste to a landfill. Wastes are disposed of upon receipt and variable landfill costs are realized in the objective function.

$$\sum_k GS_{kj} = VS_{ij}, \quad \text{for all } j \text{ and all } i \qquad (5)$$

Equation 6 is the capacity constraint for landfill size i. $CAPACITY_i$ is the amount of waste that can be accepted at a landfill of a particular size (i.e., 20, 75, 175, 250 or 400 TPD). The amount will vary depending on the size of landfill selected by the model.

$$\sum_i \sum_j CAPACITY_i * IS_{ij} \geq VS_{ij} \tag{6}$$

The final constraint (Equation 7) only allows one landfill to be built at any particular site. IS_{ij} is a binary integer. This forces the model to either build a landfill or not. Landfills were assumed to be of a definite size (20, 75, 175, 250, or 400 TPD). Potentially landfills could be of any size. However, the increase in modelling complexity that would result from using a continuous landfill cost function was judged to be unnecessary.

$$\sum_i IS_{ij} \leq 1, \quad \{0,1\} \quad \text{for all } j \tag{7}$$

WASTE GENERATION SITES

Specific waste generation sites and potential landfill sites must be specified and the distances between them must be calculated to make the model operational. Since MSW is generated wherever people live, there could potentially be as many waste generation sites as households. Therefore, it was necessary to develop a method of attributing waste quantities to a reasonable number of discrete locations. The state was divided into wastesheds for two primary reasons. First, transportation costs are disaggregated with small geographic units. Second, population distribution was handled more accurately with small geographic units. Costs were more accurate with the combination of geographic breakdown of population and refined transportation costs.

The 17 urban centers (cities of 2,500 or greater population) were identified as discrete waste generation sites. The remainder of the state was divided into 159 subcounty wastesheds (Figure 4). The waste generation for each was based on its population (Appendix B). The location of the wastes within each wasteshed was assumed to be a city central to the wasteshed or the city with the largest population.

The number of wastesheds per county ranged from one to eight. Three counties, Billings, Oliver, and Eddy, had one wasteshed because of their small area and/or population (Figure 4). Cass County had the most wastesheds (eight), with two urban centers plus six other subcounty wastesheds. Waste was identified for Native American reservations as requested by the North Dakota State Department of Health and Consolidated Laboratories (Figure 4). The reservations at Fort Berthold (wasteshed G175) and Fort Yates (wastesheds G044, G134, and G136) were assumed to operate their own landfills. Thus, they disposed of the waste generated on the reservation in a reservation landfill. They were not allowed to receive waste from other wastesheds or to

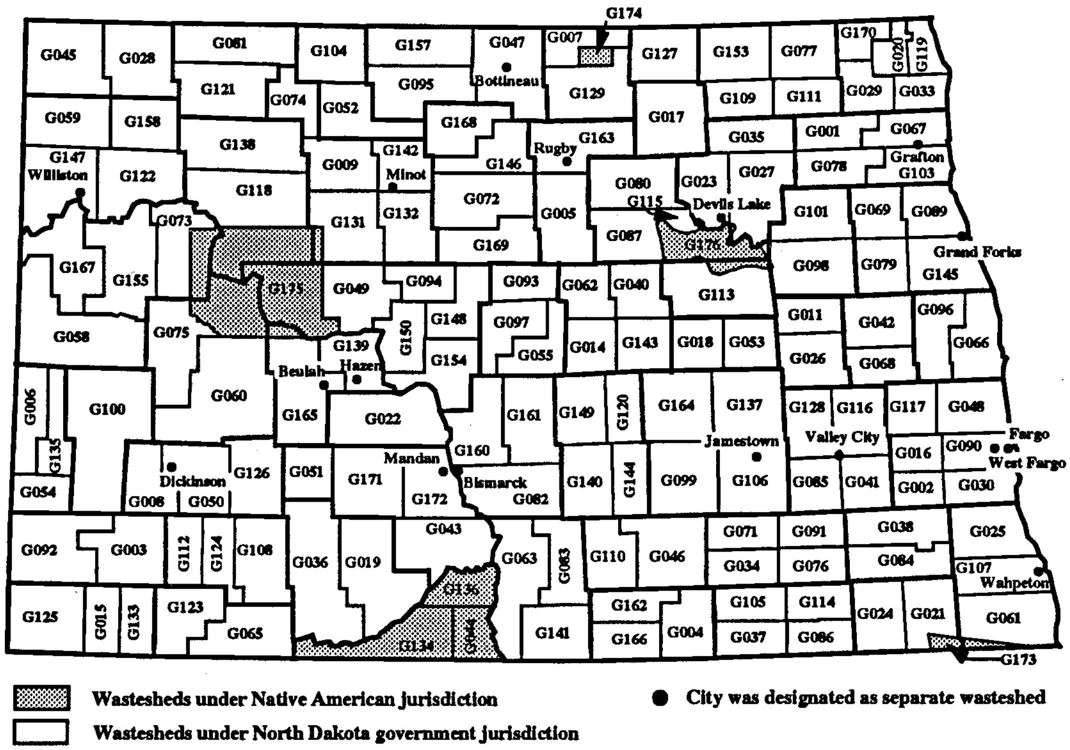


Figure 4. North Dakota Waste Generation Sheds.

ship their waste to other landfills. MSW from other Native American reservations was shipped to regional landfills.

LANDFILL SITES

Several criteria were used to select potential landfill sites for the model. At least one candidate site was selected in each county. This was the baseline scenario cost of developing a landfill there. All sites with existing landfills receiving wastes were included. If a county did not have a landfill, hypothetical sites were chosen based on two factors. First, potential sites were chosen near urban centers. Second, sites were located adjacent to state or federal highways. Except for existing landfill locations, the landfill sites chosen are for illustrative purposes only. Neither engineering nor public attitude studies were performed to assess the feasibility of any of the sites. As a result of this process, 59 potential landfill sites were selected (Figure 5).

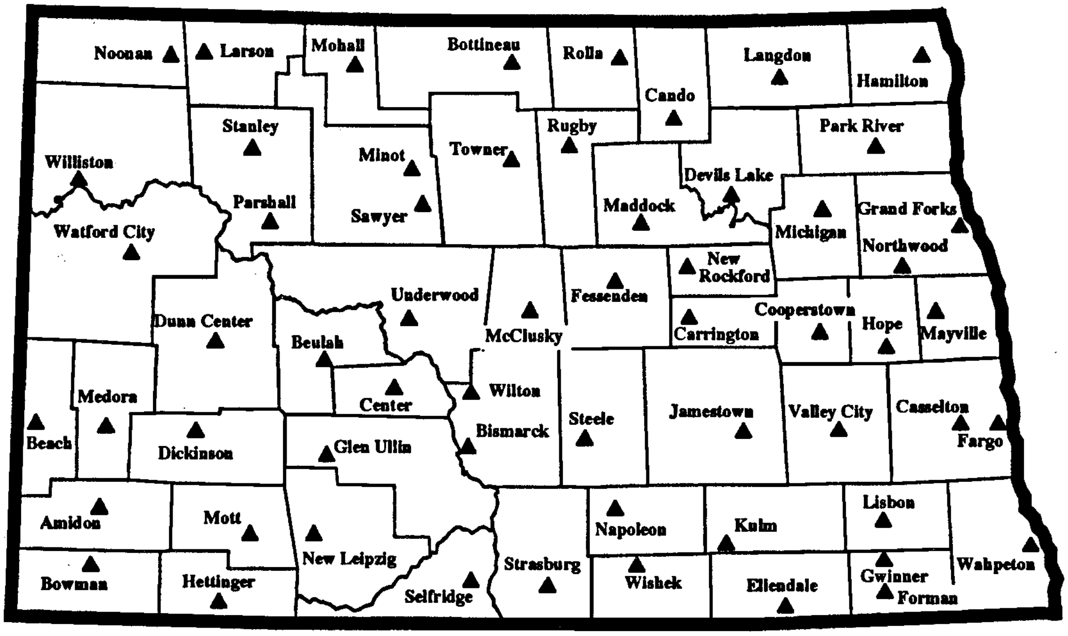


Figure 5. Possible Landfill Sites in North Dakota, 1992.

DISTANCE CALCULATIONS

Distances from wastesheds to landfill sites (arcs) were measured to calculate the cost of transporting wastes from generation to disposal locations. The number of *possible* arcs was 10,384--the number of wastesheds (176) multiplied by the number of landfill sites (59). When a wasteshed centroid and landfill site were located nearby (44 cases), a distance of one mile was assigned.

Arcs judged implausible on the basis of distance were eliminated. The North Dakota State Department of Health and Consolidated Laboratories (1992) indicated that wastes likely will not be transported farther than 160 miles round trip. This distance was used as an initial upper bound in determining which arcs were relevant for inclusion in the model. However, this distance was extended to around 200 miles round trip to allow the model to determine the least cost solution. About 1,400 of the possible arcs were estimated and included in the model.

EMPIRICAL RESULTS

The model was used to estimate the number, sizes, and locations of landfills in North Dakota that would minimize the total cost of landfill development, operation, and waste transportation, excluding collection costs. Results for each scenario are summarized. Detailed cost information at the county level is included (Appendix C).

SCENARIO A - BASELINE

An initial scenario with a landfill in each county was specified to provide a benchmark or basis for comparison.[3] The initial scenario with a landfill in each county probably represents an upper limit with which to compare the costs associated with various model solutions. This benchmark case is similar to the current situation (the state had 50 permitted landfills in 1991).

The landfill size in the initial scenario provided adequate capacity for the annual quantity of wastes generated in the county. In the five counties with two landfill sites, the site nearest the largest city was arbitrarily chosen for the initial scenario. Waste was not allowed to cross county lines. Three counties (Burleigh, Grand Forks, and Ward) required 175-TPD landfills, while Cass County needed a 250-TPD facility (Table 7). Thirteen counties had 75-TPD landfills while the other 37 sites had 20-TPD landfills.

The estimated total annual cost of MSW transportation and disposal for the baseline scenario was $16.9 million (Table 7). Fixed costs of $10.9 million made up about 65 percent of total costs. Variable costs accounted for 23.3 percent of total cost and transportation costs for 12.1 percent (Table 7).

For the baseline scenario, the weighted average total cost (ATC) was $36.20 per ton (Table 7). Perhaps more noteworthy than the statewide ATC was the variation in costs among counties (Figure 6). The ATC per ton ranged from $17 in Cass County to $229 in Slope County (Appendix Table C1). Of the state's 53 counties, ATC was greater than $50 in 33 counties, while four counties had ATC less than $21 (Appendix Table C1). Rural counties with small populations had higher costs. The state's four largest urban centers had lower costs. High ATC for many of the state's less populous counties support the need for a regional approach in developing MSW facilities.

A modification of Scenario A was to reduce the assumed waste generation rates for rural residents. Rural residents are defined as those living in or outside of towns with

---

[3]The landfill site for the Fort Berthold Reservation was assumed to be at Parshall in Mountrail County, although the Fort Berthold Reservation has an existing landfill on the western edge of the reservation. Also, waste from all towns within the boundaries of Fort Berthold Reservation was assumed to go to the reservation landfill, even though Parshall, and other cities within the reservation may fall under jurisdiction of the North Dakota State Government. Mountrail County was given another site at Stanley for waste generated outside the reservation.

By request from the North Dakota State Department of Health and Consolidated Laboratories, waste at Fort Berthold and Standing Rock jurisdictions was constrained to only go to the reservation landfill. Costs at Parshall and Selfridge are constant in all solutions. Since they do not change, they are not discussed in detail in the other scenarios.

TABLE 7. ANNUALIZED COST ESTIMATES, VOLUME OF WASTE, NUMBER OF LANDFILLS, AND AVERAGE TOTAL COST FOR SCENARIOS A1, A2, B, AND C, 1992

Item	Scenario			
	A1: Baseline-	A2: Baseline less ½ Rural	B: Regional	C: Recycling & Regional
ANNUAL STATEWIDE COSTS	thousand dollars			
Fixed	10,908	10,450	4,694	4,694
Variable	3,933	3,341	3,184	2,222
Transportation	2,041	1,591	4,371	3,013
TOTAL COST	16,882	15,382	12,249	9,929
	percentage			
Fixed	64.61	67.94	38.32	47.27
Variable	23.30	21.72	26.00	22.38
Transportation	12.09	10.34	35.68	30.34
OUTPUT				
Tons of Waste per Year	466,325	399,208	466,325	326,427
Number of Landfills	54	54	12	12
20 TPD	37	40	2	2
75 TPD	13	10	4	4
175 TPD	3	3	3	3
250 TPD	1	1	3	3
400 TPD	0	0	0	0
Total Landfill Utilization	60.0%	55.0%	92.6%	79.2%
AVERAGE TOTAL COUNTY COSTS	($/ton)			
Weighted Mean	36.20	38.53	26.27	30.42
Minimum	16.65	16.74	15.74	18.99
Maximum	228.66	381.33	59.40	60.83

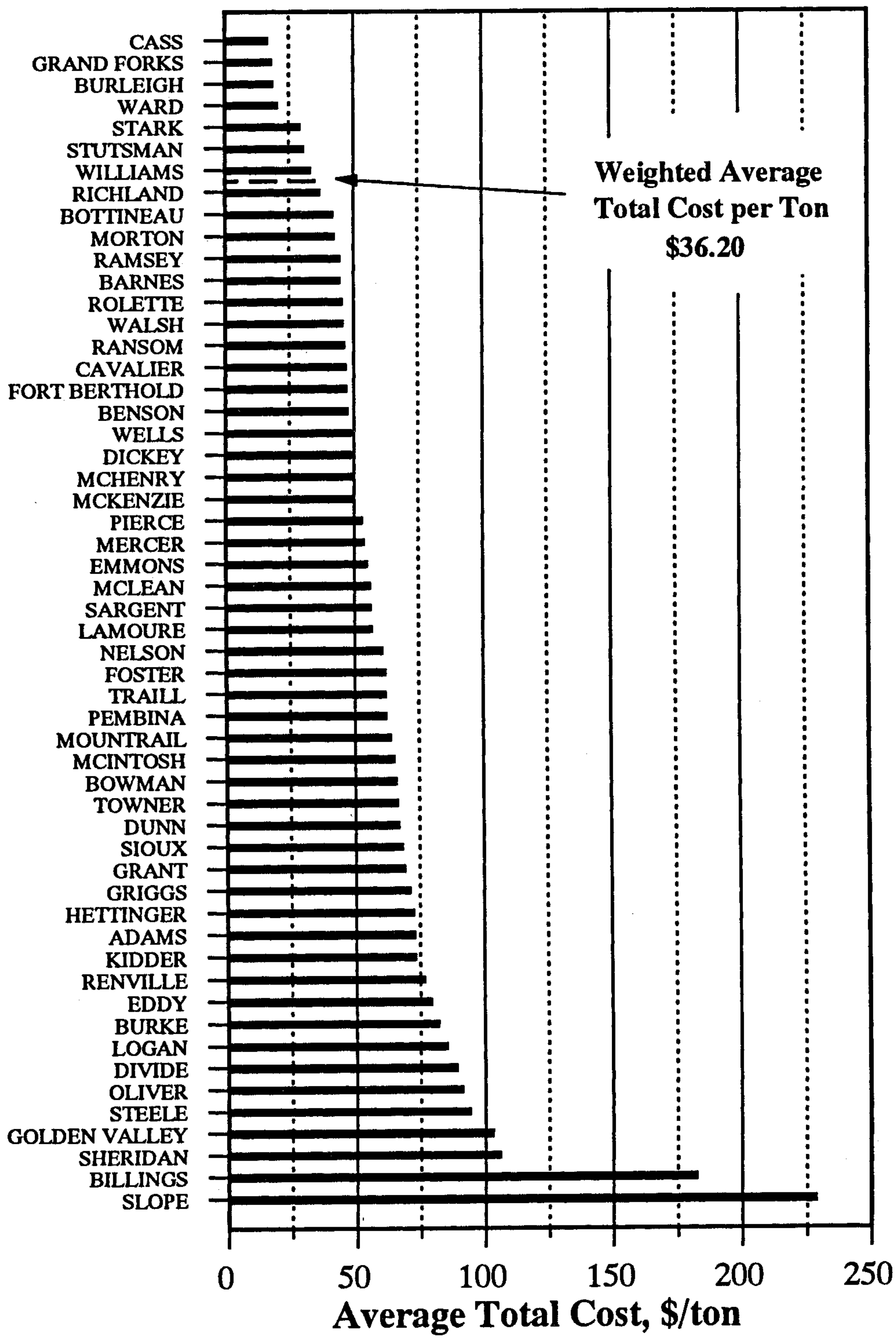


Figure 6. Distribution of County-level Waste Disposal Costs Under the Baseline Scenario (A1), 1992.

less than 75 in population. Less waste was assumed to be collected from rural residents because they dispose of their own waste.

With waste generation rates adjusted for rural residents, the tons of waste in need of disposal in the state fell 14 percent to 399,208 tons per year (Table 7). Total costs fell by $1.5 million to $15.4 million (Table 7). Costs declined for two reasons. First, less waste was handled, reducing variable and transportation costs. Second, fixed costs declined because three counties (McLean, Pembina, and Traill) built 20-TPD landfills instead of 75-TPD landfills (Appendix Tables C1 and C2).

While total cost fell, ATC rose to $38.53 per ton (Table 7). The range also widened, from a minimum of $17 to a maximum of $381 per ton (Table 7). The ATC increased because there was less waste to support the fixed cost of the landfills. ATC rose more in counties with large rural populations because their total volume of waste disposed decreased more.

SCENARIO B - REGIONALIZATION

In Scenario B, waste was allowed to move across county lines to larger, lower cost regional landfills. Some sites also were allowed to choose among different sized landfills. Compared to Scenario A, the solution to Scenario B represents the cost savings from regionalizing landfills.

The solution to Scenario B was obtained in a piecemeal fashion because the computer could not solve the statewide model with multiple sizes at 59 sites.[4] The solution to Scenario B was obtained by first solving for Regions[5] 7 and 8 in southwestern North Dakota. Most sites that did not build a landfill in the regional solution were eliminated as potential sites, thereby reducing the number of integer variables. Another region was then added and the model was solved again, eliminating more sites.

The solution to the regional scenario had twelve landfills (Table 7). Ten of the landfills were regional landfills (Figure 7). The other two served Native American reservations at Fort Berthold and Standing Rock. Three of the regional sites were 250-TPD landfills, three were 175 TPD, and the other four were 75-TPD facilities (Table 8). All landfills combined operated at 93 percent of capacity (Table 8). Five facilities were at 100 percent of capacity. Of the regional landfills, Dickinson, located in the sparsely populated southwestern part of the state, had the lowest percentage capacity utilization at 71 percent (Table 8). The average total costs of MSW disposal ranged from $13.85 per ton at Bismarck to $61.23 per ton at Selfridge (Table 8).

The total annual cost of MSW transportation and disposal for the optimal solution was estimated to be $12.2 million (Table 7). Compared to the unrealistic baseline solution

---

[4]Mixed integer programming models are solved by considering branches of binary decisions (build or not build). The complexity of the model increases with each additional site or size. The full state model would have to consider 2^{102} possible solutions.

[5]State planning regions as established by State Century Code § 23-29.

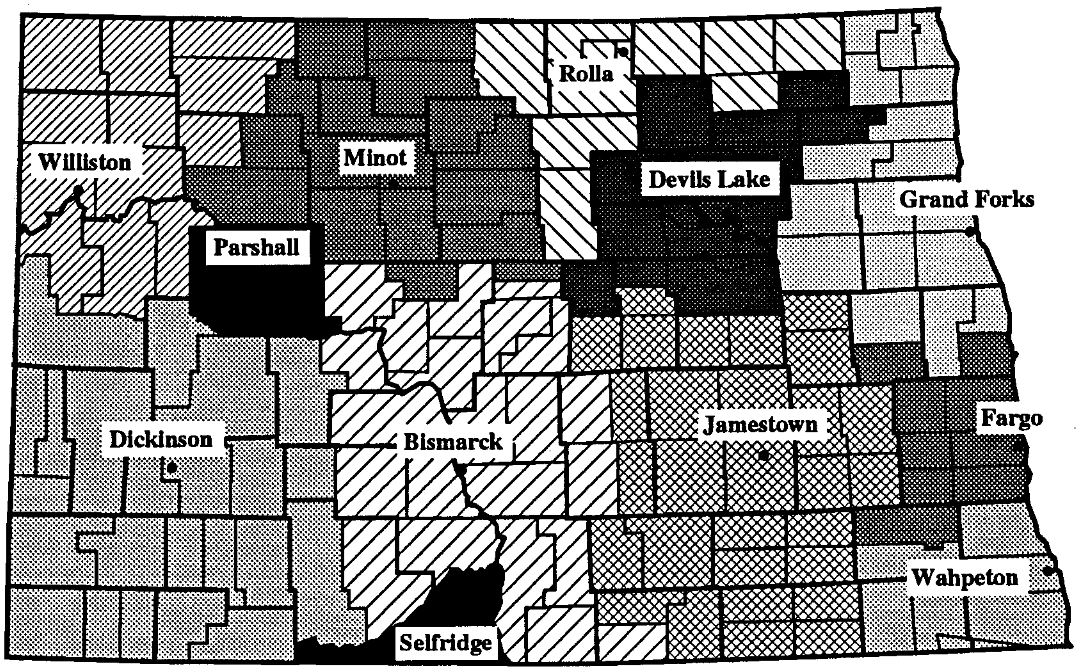


Figure 7. Waste Draw Areas and Landfill Locations for Scenario B, 1992.

(i.e., one landfill per county), the total cost of MSW transportation and disposal in the regional solution fell by 27 percent (Table 7).

Total fixed costs fell 57 percent between the baseline and optimal solution to $4.7 million (Table 7). Total fixed costs decreased between the two solutions because the number of landfills constructed fell from 53 to 12 (Table 7). Variable costs fell 19 percent to $3.2 million. Variable costs per ton were lower at the larger sized landfills. Transportation costs increased substantially (114 percent) to $4.4 million, reflecting the increased distance when shipping MSW to regional facilities. Fixed costs were less dominant in terms of total cost, accounting for 38 percent instead of 65 percent (Table 7).

The weighted average cost per ton for solid waste transportation and landfilling decreased by 27 percent in the optimal solution, averaging $26.27 per ton compared to $36.20 per ton in the baseline case (Table 7). As expected, the state's least populous counties had the largest cost reductions as a result of a regional approach to MSW management (Figure 8). The maximum cost was $59 instead of $228. The ATC declined slightly in the most populous counties.

SCENARIO C - RECYCLING

In Scenario C, the sites and landfill sizes selected in Scenario B were fixed, but MSW was reduced 30 percent. Scenario C reflects the potential statewide effect of recycling programs. If recycling programs are implemented after landfills are built, there will be excess capacity or longer useful life for the landfills.

TABLE 8. SITES, UTILIZATION, TOTAL AND AVERAGE TOTAL COST ESTIMATES FOR SCENARIO B, 1992

Site	MSW	Landfill Capacity	Capacity Utilization	Annualized Total Cost	Average Total Cost
	-tons/year-	-tons/year-	--percent--	----000 $----	---($/ton)---
Bismarck	78,000	78,000	100.0	1,080.7	13.85
Fargo	78,000	78,000	100.0	1,093.1	14.01
Minot	54,600	54,600	100.0	815.2	14.93
Devils Lake	23,400	23,400	100.0	510.5	21.82
Williston	23,400	23,400	100.0	509.5	21.77
Grand Forks	77,648	78,000	99.6	1,089.0	14.02
Rolla	21,221	23,400	90.7	489.1	23.05
Jamestown	45,646	54,600	83.6	755.7	16.56
Wahpeton	19,095	23,400	81.6	475.7	24.91
Dickinson	38,631	54,600	70.8	708.9	18.35
Ft. Berthold	3,938	6,240	63.1	182.5	46.35
Selfridge	2,746	6,240	44.0	168.1	61.23
TOTALS	466,325	503,880	92.6	7,878.0	16.89

Compared to Scenario B, total costs declined by 19 percent to $9.9 million (Table 7). Variable and transportation costs both fell because less waste was handled. Fixed costs remained the same because the landfill sites were fixed. The ATC of landfill costs increased 16 percent, or $4.15 per ton to $30.42 per ton (Table 7). Other costs also increased because the solution did not consider recycling program costs.

The utilization of landfills fell from 92.6 to 79.2 percent (Table 7). The model was re-estimated allowing the sites to choose the appropriate size landfill with recycling. Smaller landfills could be built at Dickinson, Grand Forks, Jamestown, and Rolla if recycling programs reduce waste 30 percent. In the re-estimated model, the landfill at Wahpeton was not built.

SCENARIO D - TRANSSHIPMENT

In Scenario D, waste management complexity increased as transfer stations were added. Landfill sites that did not enter the solution in Scenario B were converted to possible transfer stations since transfer links between wastesheds and those sites already existed. Additional links from transfer stations (unused landfill sites) to regional landfill sites were included. Due to programming complexities and time constraints, *all* possible locations for transfer stations were not addressed. To determine the location and size of transfer stations throughout the state in a method similar to that employed for landfills

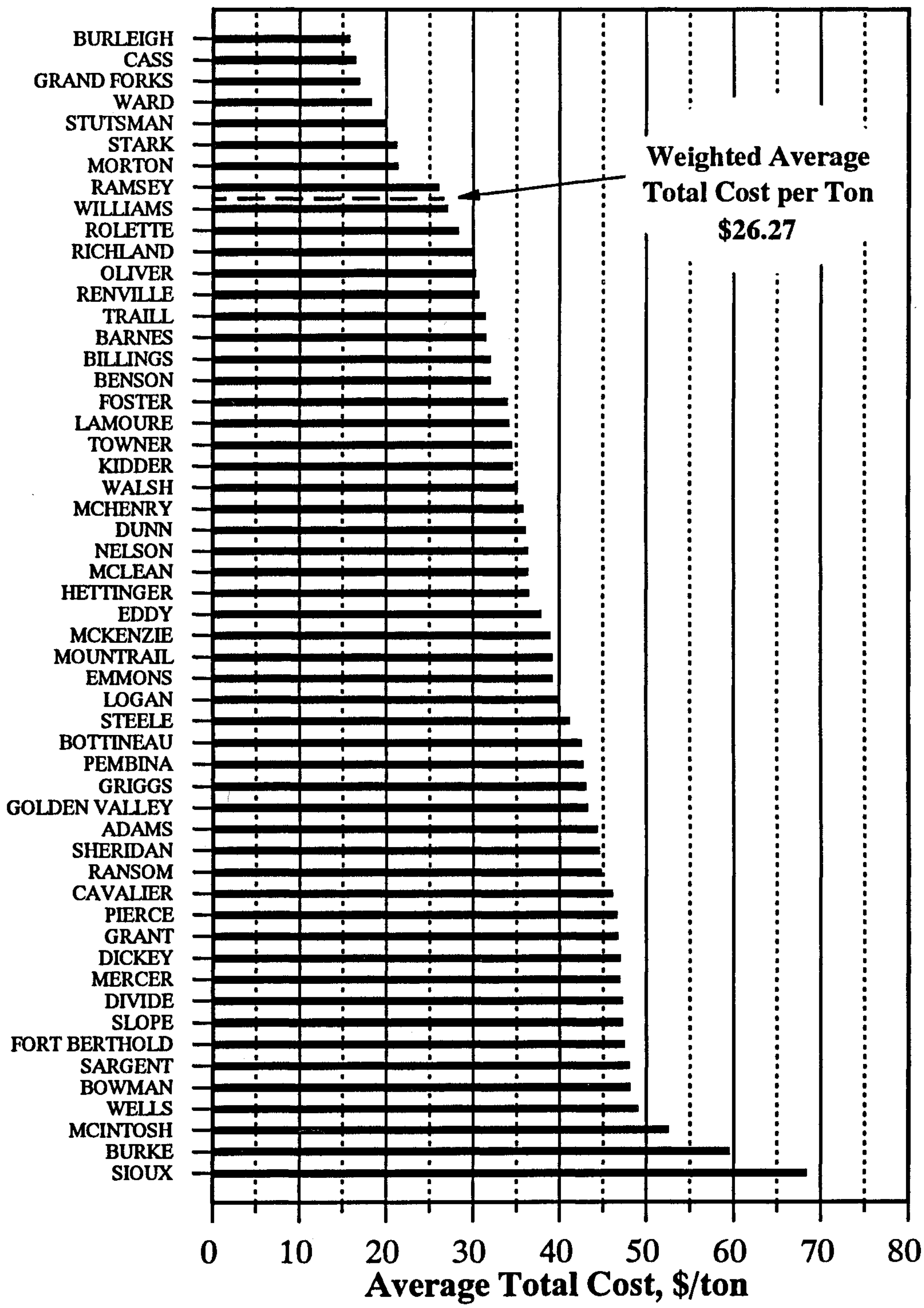


Figure 8. Distribution of County-level Waste Disposal Costs Under Scenario B, 1992.

was beyond the scope of the study. Thus, the solution to Scenario C should not be interpreted to mean that transfer stations *should be* built at these sites, but rather, that transfer stations *might be* feasible at these locations. The results from Scenario D indicate if transfer stations, given current costs and capacities, can generate additional savings by transporting waste through transfer facilities rather than shipping directly to landfills.

Four different options were considered in Scenario D to test model sensitivity to transfer costs (Table 9). Changing the transfer station operating cost varies the break-even point between shipping direct to a landfill or through a transfer station. With

TABLE 9. ASSUMPTIONS AND VOLUME OF WASTE HANDLED FOR SCENARIO D, TRANSSHIPMENT

Item	Scenario D1	Scenario D2	Scenario D3	Scenario D4
ASSUMPTIONS				
Compaction Truck Cost per Ton-Mile	$0.20	$0.20	$0.20	$0.20
Semitrailer Cost per Ton-Mile	$0.04	$0.04	$0.04	$0.04
Transfer Station Operating Cost per Ton	$8.00	$12.00	$8.00	$12.00
Break-even Point (in miles)	50	75	50	75
Transfer Station Capacity (Tons per year)	3,744	3,744	5,616	5,616
WASTE HANDLED				
Number of Transfer Stations at Capacity	15	10	5	3
Number of Transfer Stations Receiving 2,000 TPY to Capacity	16	14	25	20
Number of Transfer Stations Receiving less than 2,000 TPY	11	14	11	15
Number of Transfer Stations Handling Waste	42	38	41	38
Tons of Waste per Year Hauled Direct to Landfills	356,134	372,889	347,645	368,372
Tons of Waste per Year Transshipped	110,191	93,436	118,680	97,953
Total Tons of Waste per Year	466,325	466,325	466,325	466,325

compaction truck costs of $0.20 per ton-mile, semi-truck costs of $0.04 per ton-mile, and transfer station costs of $8 per ton, the break-even point was 50 miles (Scenario D1). If a wasteshed was within 50 miles of the landfill, it was cheaper to ship directly to the landfill. Wastesheds farther than 50 miles should use transfer stations. Increasing the transfer station cost to $12 per ton and leaving transportation costs the same increased the break-even point to 75 miles (Scenario D2). Scenario D was also solved with two sizes of transfer stations, 12 TPD (Scenarios D1 and D2) and 18 TPD (Scenarios D3 and D4). Unlike the landfill sites, the model did not separately consider the fixed and variable costs of transfer stations.

Compared to Scenario B, the number and sites of landfills were the same. However, different sized landfills were built. By adding transfer stations, the landfill at Devils Lake was larger (175 TPD versus 75 TPD), while landfills at Grand Forks (175 TPD from 250 TPD) and Rolla (20 TPD from 75 TPD) were smaller (Table 10). Transfer stations increased the draw area for some landfills. The solution was quite stable, with the sizes and sites remaining constant in all four options (Table 11).

In comparison to Scenario B, total costs decreased by 7 percent to $11.3 million (Tables 7 and 11). Fixed costs were less because different sized landfills were built. Variable costs increased 26 percent to $4.0 million because it included the operating costs at transfer stations. Transportation costs decreased 37 percent to $2.8 million because some waste was shipped by semitrailers rather than compaction trucks.

In the four options, waste was handled at 38 to 42 of the 47 possible transfer stations (Table 9). However, the number of transfer stations operating at capacity was lower, between 3 and 15 (Table 9). On average, 25 percent of the transfer stations ship less than 2,000 TPY or 6 TPD. The amount of waste transshipped was between 20 and 25 percent of the total waste.

SCENARIO E - INCINERATOR

Grafton might build a 75- to 100-TPD incinerator[6] (Schock 1992). Park River, which is 22 miles west of Grafton, was the landfill site for Walsh County. Since there were no transportation links to Grafton, Scenario E was solved assuming the incinerator was built at Park River rather than Grafton. The model was solved assuming that at least 75 TPD of MSW must be received at Park River. The incinerator could receive up to 175 TPD.

In Scenario E all waste generated and shipped to Park River was assumed to be incinerated. However, some MSW cannot be incinerated and must be buried. Thus, the model results underestimated the draw area for the incinerator. In addition, issues related to the disposal of incinerator ash were not addressed.

[6]Secondary cost estimates for building and operating an incinerator were not found. Thus, the incinerator was assumed to have the same fixed and operating costs as a landfill of the same size.

TABLE 10. WASTE HANDLED AT LANDFILLS FOR SCENARIOS B, D1, E, F, G, AND H

Landfill	Scenarios					
	B: Regional	D1: Transship	E: Grafton Inciner-ator	F: Fargo, Bismarck, McKenzie County "go alone"	G: Exclude Ellendale	H: Scenarios E, F, G, and Imports
	tons/year					
Bismarck	78,000	78,000	78,000	47,036^{S}	78,000	47,036^{S}
Devils Lake	23,400	54,600^{L}	23,400	23,400	23,400	23,400
Dickinson	38,631	38,415	38,631	43,015	38,631	41,239
Fargo	78,000	78,000	78,000	63,071	78,000	78,000
Grand Forks	77,648	54,600S	54,600^{S}	78,000	77,648	75,039
Jamestown	45,646	54,600	48,386	54,600	43,911	46,208
Minot	54,600	54,600	54,600	54,600	54,600	54,600
Parshall	3,938	3,938	3,938	3,938	3,938	3,938
Rolla	21,221	6,240^{S}	18,129	6,240^{S}	21,221	6,240^{S}
Selfridge	2,746	2,746	2,746	2,746	2,746	2,746
Wahpeton	19,095	17,283	19,095	33,364^{L}	19,095	0
Williston	23,400	23,303	23,400	22,655	23,400	22,643
Park River	0	0	23,400	0	0	23,400
Rugby	0	0	0	6,240	0	6,240
Watford City	0	0	0	4,020	0	4,020
Wilton	0	0	0	23,400	0	23,400
Gwinner	0	0	0	0	0	50,301
TOTAL	466,325	466,325	466,325	433,325	464,590	508,450

NOTE: The ^{S} means the landfill was a smaller size than in the Scenario B solution, while ^{L} means a larger landfill.

The model selected a 75-TPD incinerator at Park River. Compared to Scenario B, the only major difference was that Grand Forks built a 175-TPD landfill rather than a 250-TPD landfill (Table 10). All other landfills were the same size and received about the same volume of MSW as in Scenario B (Table 10).

TABLE 11. ANNUALIZED COST ESTIMATES, VOLUME OF WASTE, NUMBER OF LANDFILLS, AND AVERAGE TOTAL COST FOR SCENARIOS D1, D2, D3, AND D4, 1992

Item	Scenarios			
	D1: 50 miles/Low Capacity	D2: 75 miles/Low Capacity	D3: 50 miles/High Capacity	D4: 75 miles/High Capacity
ANNUAL STATEWIDE COSTS	thousand dollars			
Fixed	4,550	4,550	4,550	4,550
Variable	4,003	4,247	4,075	4,301
Transportation	2,754	2,919	2,642	2,844
TOTAL COST	11,307	11,716	11,267	11,695
	percentage			
Fixed	40.2	38.8	40.4	38.9
Variable	35.4	36.3	36.2	36.8
Transportation	24.4	24.9	23.4	24.3
OUTPUT				
Tons of Waste per Year	466,325	466,325	466,325	466,325
Number of Landfills	12	12	12	12
20 TPD	3	3	3	3
75 TPD	2	2	2	2
175 TPD	5	5	5	5
250 TPD	2	2	2	2
400 TPD	0	0	0	0
Landfill Utilization	94.3%	94.3%	94.3%	94.3%
AVERAGE TOTAL COUNTY COSTS	($/ton)			
Weighted Mean	24.25	25.12	24.16	25.08
Minimum	15.74	15.74	15.74	15.74
Maximum	45.69	49.38	45.69	62.41

Compared to Scenario B, total costs and ATC were almost identical (Tables 7 and 12). The composition of costs was slightly different. Fixed and variable costs were somewhat higher in Scenario E, primarily because an additional facility was operating. However, an additional facility decreased transportation costs. If ash and unburned waste disposal costs were to be included, total costs for this scenario would likely increase.

SCENARIO F - GO ALONE

Rather than participate in regional landfills, some communities might build and operate their own landfill. In Scenario F, Bismarck-Mandan, Fargo-West Fargo, and McKenzie County were assumed to only receive waste from their jurisdiction.
In the solution to Scenario F, Bismarck built a 175-TPD landfill instead of a 250-TPD landfill (Table 10). Rolla also built a smaller landfill (20 TPD instead of 75 PD), while Wahpeton built a larger landfill (175 TPD instead of 75 TPD). If the three sites "go alone," the state will open three additional landfills. Rugby and Watford City built 20-TPD landfills and Wilton built a 75-TPD landfill. Wilton receives waste from the area formerly served by Bismarck. Statewide, the landfill utilization rate dropped to 88 percent (Table 12).

A decision to "go-alone" by the three jurisdictions mentioned would increase total costs by 7 percent to $13.1 million (Tables 7 and 12). Fixed costs increased 9 percent to $5.1 million because more landfills were built (Table 12). Variable costs increased slightly to $3.2 million. Transportation costs also increased 8 percent to $4.7 million (Table 12). ATC rose $1.85 per ton to $28.12 per ton (Table 12).

SCENARIO G - NO WASTE FROM ELLENDALE

Ellendale, at the time this study was conducted, shipped its waste to South Dakota. Scenario G was identical to Scenario B except that the 1,735 tons of waste per year generated at Ellendale are not included.[7] The solution was almost identical to Scenario B, except Jamestown received less waste (Table 10).

SCENARIO H - COMBINE E, F, AND G AND IMPORTS

The final scenario combines most of the assumptions of Scenarios E, F, and G. In addition, out-of-state waste was imported to Fargo, Grand Forks, and Gwinner. Links were added requiring a certain level of waste be shipped to particular landfills. Fargo was assumed to receive 10 TPD, Grand Forks receive 20 TPD, and Gwinner receive 40 TPD. No trucking cost was assigned to the imported waste since that cost is borne out-of-state. One modification to the Scenario F assumptions was required. Since Fargo could receive waste from out-of-state, it also was free to collect MSW from North Dakota wastesheds.

---

[7]Ellendale has since contracted to ship its MSW to a landfill in North Dakota, effective in January 1993.

TABLE 12. ANNUALIZED COST ESTIMATES, VOLUME OF WASTE, NUMBER OF LANDFILLS, AND AVERAGE TOTAL COST FOR SCENARIOS E, F, G, AND H, 1992

Item	Scenarios			
	E: Grafton Incinerator	F: Go Alone	G: No Ellendale	H: E, F, & G and Imports
ANNUAL STATEWIDE COSTS	thousand dollars			
Fixed	4,823	5,120	4,694	5,757
Variable	3,289	3,265	3,173	3,415
Transportation	4,136	4,729	4,325	4,086
TOTAL COST	12,248	13,113	12,192	13,258
	percentage			
Fixed	39.4	39.0	38.5	43.4
Variable	26.8	24.9	26.0	25.8
Transportation	33.8	36.1	35.5	30.8
OUTPUT				
Tons of Waste per Year	466,325	466,325	464,951	508,271
Number of Landfills	13	15	12	16
20 TPD	2	5	2	5
75 TPD	5	3	4	4
175 TPD	4	5	3	5
250 TPD	2	2	3	2
400 TPD	0	0	0	0
Total Landfill Utilization	92.5%	87.9%	92.2%	91.8%
AVERAGE TOTAL COUNTY COSTS	($/ton)			
Weighted Mean	26.27	28.12	26.24	26.09
Minimum	15.74	16.77	15.74	16.94
Maximum	59.43	59.84	59.43	61.66

With 16 landfills, the solution to Scenario H had the most landfills (Table 10). More landfills were built because of the assumptions of Scenarios E and F and because of the extra 80 TPD of imported waste. Compared to Scenario B, Bismarck and Rolla build smaller landfills. No landfill was constructed at Wahpeton, probably because waste was drawn to Gwinner (Figure 9). The utilization rate stayed at 92 percent because of imports (Table 12).

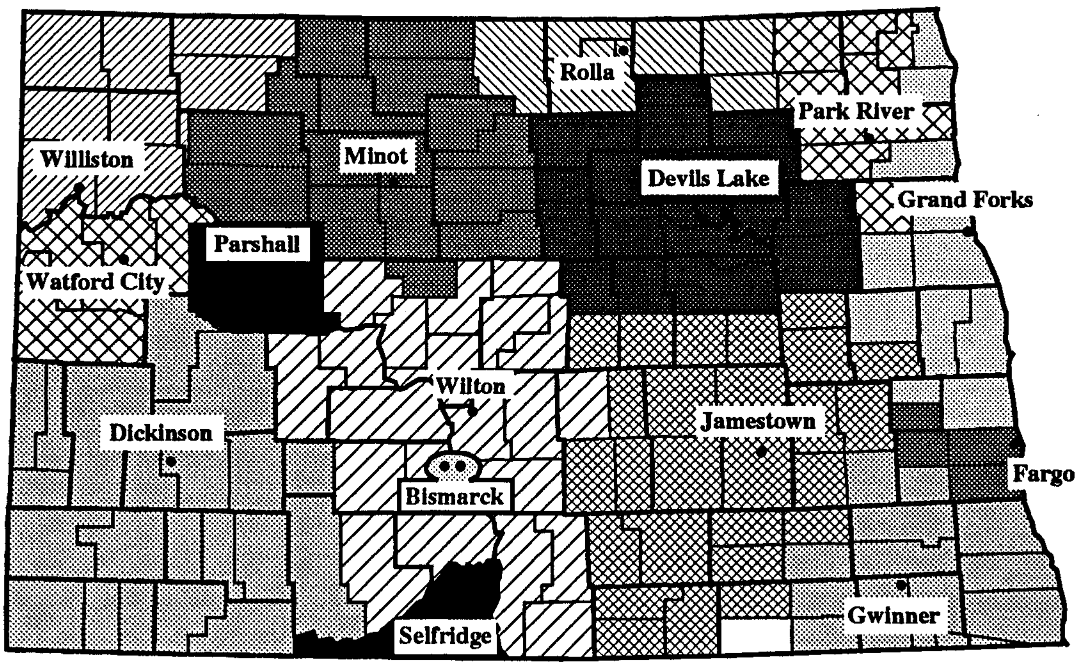


Figure 9. Waste Draw Areas and Landfill Locations Under Scenario H, 1992.

Except for Scenario A (the baseline), total costs for Scenario H are the highest of the other scenarios (Figure 10). Total costs are $13.3 million, which was $1.1 million or 8 percent more than Scenario B's total cost (Tables 7 and 12). At $5.8 million, fixed costs are 23 percent higher because of the additional landfills (Table 12). Variable costs increased 7 percent because smaller landfills are used and because of the additional imported waste. Transportation costs, which are not calculated for imported waste, increased 7 percent to 4.1 million dollars. The composition of costs shifted to a greater emphasis on fixed costs.

CONCLUSIONS AND IMPLICATIONS

Providing for environmentally acceptable management of municipal solid waste at an acceptable cost is a challenge to local and state officials and planners. New requirements for landfill design and operation, commonly known as Subtitle D

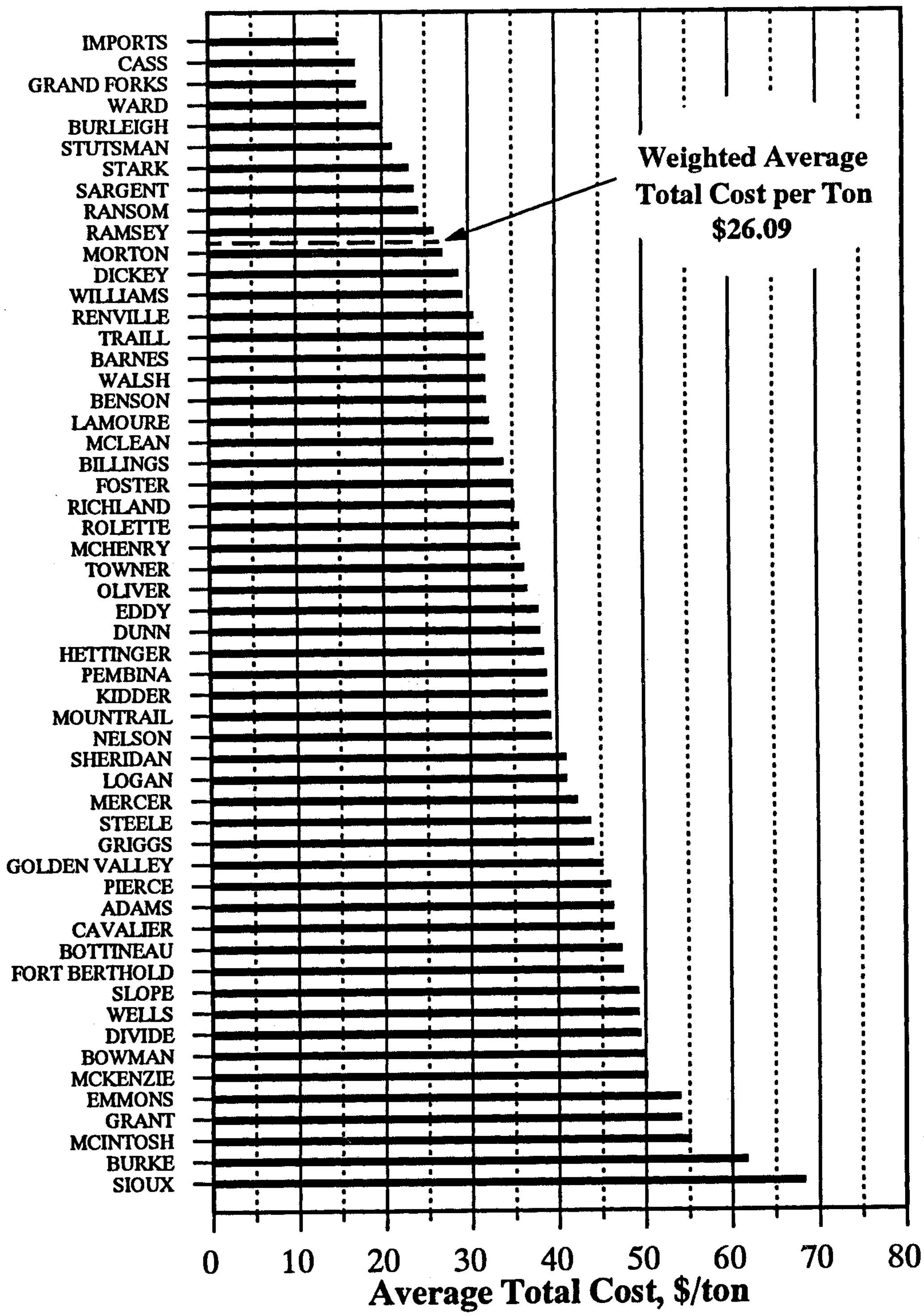


Figure 10. Distribution of County-level Waste Disposal Costs Under Scenario H, 1992.

regulations, will require most existing facilities to be replaced or extensively redesigned. A major effect of the Subtitle D regulations is to place more emphasis upon economies of size in landfill development and operation. Small, community-based landfills will no longer be economically feasible.

The findings of this study highlight waste disposal costs facing North Dakota's smaller communities, particularly those remote from urban centers. If each county was required (or elected) to develop its own landfill facility, MSW disposal costs would be more than $50 per ton to comply with Subtitle D, in almost half of the state's counties. The total cost was even higher because this model does not include collection expenses. For these counties in particular, a considerable economic incentive exists for arriving at an acceptable regional plan for MSW management.

The results of the various models are stable.

- Regardless of the scenario, no 400-TPD landfill was built. North Dakota does not appear to have sufficient levels of MSW generated in close proximity which could allow a 400-TPD landfill to be built. In order to operate a 400-TPD landfill at capacity, waste would have to be shipped from long distances, which generates transportation costs that more than offset any savings (economies of scale) realized by building and operating a larger landfill.

- The same size landfill was built in the solutions to Scenarios B - H at Dickinson, Fargo, Jamestown, Minot, and Williston.

- If Bismarck-Mandan built a local landfill rather than a regional one, they should build a 175 TPD rather than a 250-TPD landfill. However, another landfill will have to be built in the vicinity.

- Devils Lake increases the size of its landfill with transshipment, drawing waste from Grand Forks and Rolla.

- The decision of what size of landfill to build at Grand Forks depends on decisions made at Devils Lake and Grafton.

- A landfill is required at Rolla because there is a concentrated amount of waste far from regional landfills.

- In Scenario H, Wahpeton does not build a landfill. The decision to build at Wahpeton was contingent on decisions at Fargo and Gwinner.

- If the rural population disposes of their own waste, the total cost of waste disposal will fall. However, the average total cost per ton will increase because landfill utilization will fall.

- Statewide recycling programs could result in excess landfill capacity. Under the recycling scenario, total costs decreased, but average costs per ton increased.

- Building landfills on the reservations at Fort Berthold and Fort Yates was costly. The ATC was $47.35 at Fort Berthold and $68.28 per ton at Fort Yates. In comparison, the ATC in the rest of the state was $26 to $28 per ton.

In summary, the numbers and locations of landfills and disposal costs were stable from model to model. However, Scenario H demonstrates that local jurisdiction decisions affect regional landfills statewide. Thus, when permitting landfills, the presence of other landfills is an important factor.

This analysis was limited to cost tradeoffs between disposal and transportation. Other landfill costs (e.g., externalities, truck traffic, aesthetics, local opinion) were ignored because they are difficult to objectively quantify. Nevertheless, this analysis provides a basis to consider these other issues.

REFERENCES

Buell, Deems, Kevin Dietly, Ron Burke, Patricia Robertson, and Sara Rasmussen. 1990. "Economic Incentives and Trends for Regionalization of Municipal Solid Waste Landfills." Paper presented at the First U.S. Conference on Municipal Solid Waste Management, June 13-26, Washington, D.C.

Fischer, William R. 1992. "Minimizing the Cost of Solid Waste Landfilling in North Dakota." M.S. Thesis, Department of Agricultural Economics, North Dakota State University, Fargo.

Halbach, Myrna M. 1990. *Financial Assurance for Land Disposal Facilities: The North Dakota Solid Waste Symposium.* U.S. Environmental Protection Agency, Bismarck, North Dakota.

Joyce, Leonard E. Jr. 1990. "How to Calculate Waste Disposal Costs." *Government Finance Review.* August, pp. 20-21, 48.

Lobb, Everett. 1970. *Solid Waste in North Dakota.* North Dakota State Department of Health, Division of Environmental Sanitation and Food Protection, Bismarck, North Dakota.

Minnesota Department of Natural Resources. 1992. "Landfill Cost Analysis Spreadsheet." St. Paul, MN.

North Dakota Agricultural Statistics Service. 1992. *1992 North Dakota County Level Rents.* North Dakota Agricultural Statistics Service and United States Department of Agriculture. Fargo.

________. 1991. *County Level Rents for Agricultural Land, North Dakota, 1991.* North Dakota Agricultural Statistics Service and United States Department of Agriculture. Fargo.

________. 1990. *County Level Rents for Agricultural Land, North Dakota, 1990.* North Dakota Agricultural Statistics Service and United States Department of Agriculture. Fargo.

North Dakota State Department of Health and Consolidated Laboratories. 1992. "Guidelines for Solid Waste Management Planning in North Dakota." Bismarck.

________. 1989. "A Proposed Plan for Solid Waste Management in North Dakota." Bismarck, North Dakota.

Schock, Martin R. 1992. Personal communication. North Dakota State Department of Health and Consolidated Laboratories. Bismarck.

Schock, Martin R. 1991. "North Dakota's Municipal Waste Situation." In *Waste-To-Energy: An Integrated Approach, Proceedings of the Waste-To-Energy Conference,* Western Regional Biomass Energy Program, Denver, Colorado, #2.

Sebesta, James J. 1989. "Landfill Costs." Unpublished engineering study. OSM & Assoc., Minneapolis, Minnesota.

Tchobanoglous, George, Hilary Theisen, and Rolf Eliassen. 1977. *Solid Wastes: Engineering Principles and Management Issues.* McGraw-Hill Publishing Company. New York, New York.

U.S. Bureau of Economic Analysis. Various Years. *Survey of Current Business.* U.S. Government Printing Office, Washington, D.C.

U.S. Department of Commerce, Economics and Statistics Administration, Bureau of the Census. 1991. *1990 Census of Population and Housing: Summary Population and Housing Characteristics for North Dakota.* U.S. Department of Commerce. Economics and Statistics Administration, Washington, D.C.

U.S. Environmental Protection Agency. 1990b. *Characterization of Municipal Solid Waste in the United States: 1990 Update; Executive Summary.* Government Printing Office, Washington, D.C.

________. 1989. *Decision-Makers Guide To Solid Waste Management.* Government Printing Office, Washington, D.C.

________. 1990a. *North Dakota Solid Waste Symposium: Rural Solutions for the 1990s.* Bismarck, North Dakota.

________. 1991. "Solid Waste Disposal Criteria; Final Rule." In *Federal Register,* 40 CFR Parts 257 and 258:50978-51119, Washington, D.C.

Walsh, Patrick. 1988. "A Brief Synopsis of EPA'S Proposed Subtitle D Landfill Regulations." Community Dynamics Institute, University of Wisconsin-Madison, Madison.

APPENDIX A

County Landfill Sites and Land Cost per Acre

North Dakota, 1992

APPENDIX TABLE A1. COUNTY LANDFILL SITES, 1992 AND AVERAGE LAND COST PER ACRE, 1990-1992, NORTH DAKOTA

COUNTY	LANDFILL SITE USED IN MODEL	STATE PLANNING REGION	LAND COST[a] $/ACRE
ADAMS	HETTINGER	8	203.9
BARNES	VALLEY CITY	6	378.3
BENSON	MADDOCK	3	293.5
BILLINGS	MEDORA	8	219.9
BOTTINEAU	BOTTINEAU	2	320.1
BOWMAN	BOWMAN	8	216.4
BURKE	LARSON	2	194.3
BURLEIGH	BISMARCK	7	231.4
BURLEIGH	WILTON	7	231.4
CASS	CASSELTON	5	673.4
CASS	FARGO	5	673.4
CAVALIER	LANGDON	3	443.9
DICKEY	ELLENDALE	6	270.2
DIVIDE	NOONAN	1	253.9
DUNN	DUNN CENTER	8	211.2
EDDY	NEW ROCKFORD	3	301.3
EMMONS	STRASBURG	7	230.6
FOSTER	CARRINGTON	6	343.3
GOLDEN VALLEY	BEACH	8	265.8
GRAND FORKS	GRAND FORKS	4	602.1
GRAND FORKS	NORTHWOOD	4	602.1
GRANT	NEW LEIPZIG	7	194.3
GRIGGS	COOPERSTOWN	6	338.3
HETTINGER	MOTT	8	262.8
KIDDER	STEELE	7	184.2
LAMOURE	KULM	6	314.7
LOGAN	NAPOLEON	6	244.8
MCHENRY	TOWNER	2	258.3
MCINTOSH	WISHEK	6	225.4
MCKENZIE	WATFORD CITY	1	247.1
MCLEAN	UNDERWOOD	7	347.5
MERCER	BEULAH	7	258.9
MORTON	GLEN ULLIN	7	214.1
MOUNTRAIL	PARSHALL	2	277.7
MOUNTRAIL	STANLEY	2	277.7
NELSON	MICHIGAN	4	327.2
OLIVER	CENTER	7	226.2
PEMBINA	HAMILTON	4	884.4
PIERCE	RUGBY	2	273.0
RAMSEY	DEVILS LAKE	3	333.3
RANSOM	LISBON	5	398.5
RENVILLE	MOHALL	2	334.5
RICHLAND	WAHPETON	6	776.5
ROLETTE	ROLLA	3	271.6
SARGENT	FORMAN	5	396.9
SARGENT	GWINNER	5	396.9
SHERIDAN	MCCLUSKY	7	246.5
SIOUX	SELFRIDGE	7	144.0
SLOPE	AMIDON	8	228.4
STARK	DICKINSON	8	249.8
STEELE	HOPE	5	440.4
STUTSMAN	JAMESTOWN	6	304.1
TOWNER	CANDO	3	315.9
TRAILL	MAYVILLE	5	815.6
WALSH	PARK RIVER	4	633.5
WARD	MINOT	2	366.8
WARD	SAWYER	2	366.8
WELLS	FESSENDEN	6	319.3
WILLIAMS	WILLISTON	1	251.4

[a]Average of 1990 to 1992 county cropland values adjusted for inflation (North Dakota Agricultural Statistics Service 1992, 1991, 1990; United States Bureau of Economic Analysis).

APPENDIX B

Wasteshed Population and Waste Generation Rates, North Dakota, 1992

APPENDIX TABLE B1. WASTESHED POPULATION AND WASTESHED GENERATION RATES, NORTH DAKOTA, 1992

WASTE SHED	COUNTY	Population			Waste Generation Rates		
		Total	Rural	Urban	Baseline	Half Rural	30% Less
					tons/year		
G001	WALSH	1,461	809	652	1,066.5	771.2	711.0
G002	CASS	836	757	79	610.3	334.0	406.9
G003	SLOPE	522	498	24	381.1	190.5	254.0
G004	McINTOSH	1,544	492	1,052	1,127.1	947.5	751.4
G005	PIERCE	948	869	79	692.0	374.9	461.4
G006	GOLDEN VALLEY	1,508	303	1,205	1,100.8	990.2	733.9
G007	ROLETTE	2,650	1,559	1,091	1,934.5	1,365.5	1,289.7
G008	STARK	1,903	694	1,209	1,389.2	1,135.9	926.1
G009	WARD	3,080	1,254	1,826	2,248.4	1,790.7	1,498.9
G010	MERCER	3,363	0	3,363	2,455.0	2,455.0	1,636.7
G011	GRIGGS	895	662	233	653.4	411.7	435.6
G012	BURLEIGH	49,256	0	49,256	35,956.9	35,956.9	23,971.3
G013	BOTTINEAU	2,598	0	2,598	1,896.5	1,896.5	1,264.4
G014	WELLS	736	448	288	537.3	373.8	358.2
G015	BOWMAN	2,335	594	1,741	1,704.6	1,487.7	1,136.4
G016	CASS	1,011	574	437	738.0	528.5	492.0
G017	TOWNER	2,732	801	1,931	1,994.4	1,702.0	1,329.6
G018	FOSTER	3,104	837	2,267	2,265.9	1,960.4	1,510.6
G019	GRANT	1,367	941	426	997.9	654.4	665.3
G020	PEMBINA	2,984	893	2,091	2,178.3	1,852.4	1,452.2
G021	SARGENT	2,729	1,096	1,633	1,992.2	1,592.1	1,328.1
G022	OLIVER	2,381	1,555	826	1,738.1	1,170.6	1,158.8
G023	RAMSEY	2,519	2,401	118	1,838.9	962.5	1,225.9
G024	SARGENT	1,672	903	769	1,220.6	891.0	813.7
G025	RICHLAND	2,342	1,692	650	1,709.7	1,092.1	1,139.8
G026	GRIGGS	2,408	957	1,451	1,757.8	1,408.5	1,171.9
G027	RAMSEY	1,201	912	289	876.7	543.9	584.5
G028	DIVIDE	692	664	28	505.2	252.6	336.8
G029	PEMBINA	1,517	1,120	397	1,107.4	698.6	738.3
G030	CASS	5,397	3,332	2,065	3,939.8	2,723.6	2,626.5
G031	RAMSEY	7,782	0	7,782	5,680.9	5,680.9	3,787.2
G032	STARK	16,097	0	16,097	11,750.8	11,750.8	7,833.9
G033	PEMBINA	1,840	435	1,405	1,343.2	1,184.4	895.5
G034	LAMOURE	1,863	669	1,194	1,360.0	1,115.8	906.7
G035	RAMSEY	1,176	561	615	858.5	653.7	572.3
G036	GRANT	2,182	1,091	1,091	1,592.9	1,194.6	1,061.9
G037	DICKEY	2,376	522	1,854	1,734.5	1,544.0	1,156.3
G038	RANSOM	2,461	1,221	1,240	1,796.5	1,350.9	1,197.7
G039	CASS	74,111	0	74,111	54,101.0	54,101.0	36,067.4
G040	WELLS	1,293	619	674	943.9	718.0	629.3
G041	BARNES	1,269	992	277	926.4	564.3	617.6
G042	STEELE	1,566	904	662	1,143.2	813.2	762.1
G043	MORTON	1,361	1,044	317	993.5	612.5	662.4
G044	SIOUX	2,135	1,913	222	1,558.6	860.3	1,039.0
G045	DIVIDE	2,207	591	1,616	1,611.1	1,395.4	1,074.1
G046	LOGAN	1,319	759	560	962.9	685.8	641.9
G047	BOTTINEAU	2,552	2,108	444	1,863.0	1,093.5	1,242.0
G048	CASS	3,263	1,391	1,872	2,382.0	1,874.3	1,588.0
G049	MCLEAN	2,613	1,083	1,530	1,907.5	1,512.2	1,271.7
G050	STARK	3,140	2,916	224	2,292.2	1,227.9	1,528.1
G051	MORTON	2,421	606	1,815	1,767.3	1,546.1	1,178.2
G052	RENVILLE	1,055	607	448	770.2	548.6	513.4
G053	FOSTER	879	676	203	641.7	394.9	427.8
G054	GOLDEN VALLEY	378	277	101	275.9	174.8	184.0
G055	SHERIDAN	602	352	250	439.5	311.0	293.0
G056	WALSH	4,840	0	4,840	3,533.2	3,533.2	2,355.5
G057	GRAND FORKS	49,425	0	49,425	36,080.3	36,080.3	24,053.5
G058	MCKENZIE	615	615	0	449.0	224.5	299.3
G059	WILLIAMS	771	430	341	562.8	405.9	375.2
G060	DUNN	2,228	1,677	551	1,626.4	1,014.3	1,084.3
G061	RICHLAND	4,430	1,981	2,449	3,233.9	2,510.8	2,155.9
G062	WELLS	3,083	820	2,263	2,250.6	1,951.3	1,500.4
G063	EMMONS	999	759	240	729.3	452.2	486.2
G064	MERCER	2,818	0	2,818	2,057.1	2,057.1	1,371.4
G065	ADAMS	2,426	815	1,611	1,771.0	1,473.5	1,180.7

- continued -

APPENDIX TABLE B1. CONTINUED

WASTE SHED	COUNTY	Population Total	Population Rural	Population Urban	Waste Generation Rates Baseline	Waste Generation Rates Half Rural	Waste Generation Rates 30% Less
					------------	tons/year	-----------
G066	TRAIL	3,057	1,569	1,488	2,231.6	1,658.9	1,487.7
G067	WALSH	4,113	2,078	2,035	3,002.5	2,244.0	2,001.7
G068	STEELE	854	532	322	623.4	429.2	415.6
G069	GRAND FORKS	1,330	955	375	970.9	622.3	647.3
G070	STUTSMAN	15,571	0	15,571	11,366.8	11,366.8	7,577.9
G071	LAMOURE	703	619	84	513.2	287.3	342.1
G072	MCHENRY	2,454	1,107	1,347	1,791.4	1,387.4	1,194.3
G073	MCKENZIE	368	368	0	268.6	134.3	179.1
G074	WARD	1,849	529	1,320	1,349.8	1,156.7	899.8
G075	DUNN	1,421	699	722	1,037.3	782.2	691.6
G076	LAMOURE	1,958	853	1,105	1,429.3	1,118.0	952.9
G077	CAVALIER	3,488	1,247	2,241	2,546.2	2,091.1	1,697.5
G078	WALSH	1,427	890	537	1,041.7	716.9	694.5
G079	GRAND FORKS	3,833	1,303	2,530	2,798.1	2,322.5	1,865.4
G080	BENSON	1,545	902	643	1,127.9	798.6	751.9
G081	BURKE	1,795	493	1,302	1,310.4	1,130.4	873.6
G082	BURLEIGH	8,246	7,069	1,177	6,019.6	3,439.4	4,013.1
G083	EMMONS	2,330	864	1,466	1,700.9	1,385.5	1,133.9
G084	RANSOM	3,460	1,251	2,209	2,525.8	2,069.2	1,683.9
G085	BARNES	834	629	205	608.8	379.2	405.9
G086	DICKEY	713	672	41	520.5	260.2	347.0
G087	BENSON	1,558	803	755	1,137.3	844.2	758.2
G088	MORTON	15,177	0	15,177	11,079.2	11,079.2	7,386.1
G089	GRAND FORKS	11,836	11,241	595	8,640.3	4,537.3	5,760.2
G090	CASS	4,936	2,326	2,610	3,603.3	2,754.3	2,402.2
G091	LAMOURE	859	637	222	627.1	394.6	418.0
G092	SLOPE	385	241	144	281.1	193.1	187.4
G093	SHERIDAN	496	437	59	362.1	181.0	241.4
G094	MCLEAN	750	389	361	547.5	405.5	365.0
G095	BOTTINEAU	1,416	875	541	1,033.7	714.3	689.1
G096	TRAIL	5,695	1,454	4,241	4,157.4	3,626.6	2,771.6
G097	SHERIDAN	1,050	558	492	766.5	562.8	511.0
G098	NELSON	2,103	899	1,204	1,535.2	1,207.1	1,023.5
G099	STUTSMAN	1,589	909	680	1,160.0	828.2	773.3
G100	BILLINGS	1,108	1,007	101	808.8	441.3	539.2
G101	NELSON	2,306	776	1,530	1,683.4	1,400.1	1,122.3
G102	WARD	34,544	0	34,544	25,217.1	25,217.1	16,811.4
G103	WALSH	1,999	1,218	781	1,459.3	1,014.7	972.8
G104	RENVILLE	2,105	794	1,311	1,536.7	1,246.8	1,024.4
G105	DICKEY	430	368	62	313.9	157.0	209.3
G106	STUTSMAN	2,888	2,806	82	2,108.2	1,084.1	1,405.5
G107	RICHLAND	2,536	1,680	856	1,851.3	1,238.1	1,234.2
G108	HETTINGER	1,682	663	1,019	1,227.9	985.9	818.6
G109	CAVALIER	844	351	493	616.1	488.0	410.7
G110	LOGAN	1,528	598	930	1,115.4	897.2	743.6
G111	CAVALIER	863	453	410	630.0	464.6	420.0
G112	HETTINGER	1,128	465	663	823.4	653.7	549.0
G113	EDDY	2,823	947	1,876	2,060.8	1,715.1	1,373.9
G114	DICKEY	2,588	719	1,869	1,889.2	1,626.8	1,259.5
G115	BENSON	639	135	504	466.5	417.2	311.0
G116	BARNES	1,606	1,431	175	1,172.4	650.1	781.6
G117	CASS	1,033	667	366	754.1	510.6	502.7
G118	MOUNTRAIL	1,056	863	193	770.9	455.9	513.9
G119	PEMBINA	1,025	383	642	748.3	608.5	498.8
G120	KIDDER	432	339	93	315.4	191.6	210.2
G121	BURKE	1,207	799	408	881.1	589.5	587.4
G122	WILLIAMS	1,569	850	719	1,145.4	835.1	763.6
G123	ADAMS	748	474	274	546.0	373.0	364.0
G124	HETTINGER	635	367	268	463.6	329.6	309.0
G125	BOWMAN	564	378	186	411.7	273.8	274.5
G126	STARK	1,692	904	788	1,235.2	905.2	823.4
G127	TOWNER	895	654	241	653.4	414.6	435.6
G128	BARNES	1,673	1,001	672	1,221.3	855.9	814.2
G129	ROLETTE	3,016	1,087	1,929	2,201.7	1,804.9	1,467.8
G130	PIERCE	2,909	0	2,909	2,123.6	2,123.6	1,415.7
G131	WARD	1,160	801	359	846.8	554.4	564.5

- continued -

APPENDIX TABLE B1. CONTINUED

WASTE SHED	COUNTY	Population			Waste Generation Rates		
		Total	Rural	Urban	Baseline	Half Rural	30% Less
					------------ tons/year	-----------	
G132	WARD	2,809	2,490	319	2,050.6	1,141.7	1,367.0
G133	BOWMAN	697	381	316	508.8	369.7	339.2
G134	SIOUX	608	405	203	443.8	296.0	295.9
G135	GOLDEN VALLEY	222	143	79	162.1	109.9	108.0
G136	SIOUX	1,018	926	92	743.1	405.2	495.4
G137	STUTSMAN	1,527	1,144	383	1,114.7	697.2	743.1
G138	MOUNTRAIL	2,685	1,085	1,600	1,960.1	1,564.0	1,306.7
G139	MERCER	1,974	1,254	720	1,441.0	983.3	960.7
G140	KIDDER	1,508	668	840	1,100.8	857.0	733.9
G141	EMMONS	1,501	839	662	1,095.7	789.5	730.5
G142	WARD	14,438	13,610	828	10,539.7	5,572.1	7,026.5
G143	WELLS	752	531	221	549.0	355.1	366.0
G144	KIDDER	631	392	239	460.6	317.6	307.1
G145	GRAND FORKS	4,259	2,846	1,413	3,109.1	2,070.3	2,072.7
G146	MCHENRY	1,137	817	320	830.0	531.8	553.3
G147	WILLIAMS	3,653	3,653	0	2,666.7	1,333.3	1,777.8
G148	MCLEAN	1,365	555	810	996.5	793.9	664.3
G149	KIDDER	761	514	247	555.5	367.9	370.4
G150	MCLEAN	1,921	629	1,292	1,402.3	1,172.7	934.9
G151	BARNES	7,163	0	7,163	5,229.0	5,229.0	3,486.0
G152	RICHLAND	8,751	0	8,751	6,388.2	6,388.2	4,258.8
G153	CAVALIER	869	662	207	634.4	392.7	422.9
G154	MCLEAN	3,020	803	2,217	2,204.6	1,911.5	1,469.7
G155	MCKENZIE	3,230	1,446	1,784	2,357.9	1,830.1	1,571.9
G156	CASS	12,287	0	12,287	8,969.5	8,969.5	5,979.7
G157	BOTTINEAU	1,445	755	690	1,054.9	779.3	703.2
G158	WILLIAMS	2,005	534	1,471	1,463.7	1,268.7	975.8
G159	WILLIAMS	13,131	0	13,131	9,585.6	9,585.6	6,390.4
G160	BURLEIGH	1,962	1,735	227	1,432.3	799.0	954.8
G161	BURLEIGH	667	504	163	486.9	303.0	324.6
G162	MCINTOSH	1,816	498	1,318	1,325.7	1,143.9	883.8
G163	PIERCE	1,195	1,115	80	872.4	465.4	581.6
G164	STUTSMAN	666	575	91	486.2	276.3	324.1
G165	MERCER	1,599	1,073	526	1,167.3	775.6	778.2
G166	MCINTOSH	661	434	227	482.5	324.1	321.7
G167	MCKENZIE	1,294	947	347	944.6	599.0	629.7
G168	MCHENRY	1,292	623	669	943.2	715.8	628.8
G169	MCHENRY	1,645	875	770	1,200.9	881.5	800.6
G170	PEMBINA	1,872	741	1,131	1,366.6	1,096.1	911.0
G171	MORTON	1,773	747	1,026	1,294.3	1,021.6	862.9
G172	MORTON	2,968	2968	0	2,166.6	1,083.3	1,444.4
G173	SARGENT/RICHLAND	237	237	0	173.0	86.5	115.3
G174	ROLETTE	7,106	4,940	2,166	5,187.4	3,384.3	3,458.3
G175	FORT BERTHOLD	5,395	3,064	2,331	3,938.4	2,820.0	2,625.6
G176	BENSON	3,588	80	3,508	2,619.2	2,590.0	1,746.2
	STATE TOTALS	638,800	183,665	455,135	466,325.0	399,208.0	310,883.0

NOTE: Rural residents are defined as those living in or outside of towns less than 75 in population.

APPENDIX C

County-level Waste Disposal Costs Under Various Scenarios,

North Dakota, 1992

APPENDIX TABLE C1. SCENARIO A1, COUNTY-LEVEL WASTE DISPOSAL COSTS UNDER BASELINE SCENARIO, NORTH DAKOTA, 1992

County	MSW	Costs of Disposal				Average Cost
		Transport.	Fixed	Variable	Total	
	- tons/year -	dollars				- $/ton -
ADAMS	2,317	5,484	137,649	26,090	169,223	73.03
BARNES	9,158	34,709	289,997	86,542	411,249	44.91
BENSON	5,351	56,795	138,315	60,251	255,361	47.72
BILLINGS	809	809	137,768	9,108	147,684	182.59
BOTTINEAU	5,848	41,457	138,513	65,849	245,819	42.03
BOWMAN	2,625	6,162	137,742	29,558	173,462	66.08
BURKE	2,192	17,902	137,578	24,676	180,156	82.21
BURLEIGH	43,896	82,927	457,412	285,322	825,661	18.81
CASS	75,098	174,721	631,313	444,580	1,250,615	16.65
CAVALIER	4,427	19,057	139,433	49,845	208,335	47.06
DICKEY	4,458	29,993	138,142	50,198	218,334	48.97
DIVIDE	2,116	26,876	138,021	23,830	188,726	89.18
DUNN	2,664	10,655	137,703	29,994	178,352	66.96
EDDY	2,061	2,061	138,373	23,205	163,638	79.41
EMMONS	3,526	16,164	137,847	39,702	193,713	54.94
FOSTER	2,908	8,939	138,685	32,739	180,364	62.03
GOLDEN VALLEY	1,539	3,489	138,109	17,327	158,925	103.28
GRAND FORKS	51,599	143,413	465,458	335,391	944,262	18.30
GRANT	2,591	12,843	137,578	29,172	179,593	69.32
GRIGGS	2,411	5,939	138,648	27,150	171,737	71.23
HETTINGER	2,515	16,567	138,087	28,317	182,971	72.76
KIDDER	2,432	13,617	137,503	27,388	178,508	73.39
LAMOURE	3,930	40,575	138,473	44,247	223,295	56.82
LOGAN	2,078	16,136	137,953	23,402	177,491	85.40
MCHENRY	4,766	45,667	138,053	53,660	237,380	49.81
MCINTOSH	2,935	21,089	137,809	33,052	191,950	65.39
MCKENZIE	4,020	18,508	137,970	45,266	201,744	50.18
MCLEAN	7,058	40,483	289,594	66,702	396,778	56.21
MERCER	7,121	28,034	288,435	67,288	383,757	53.89
MORTON	17,301	285,897	287,849	163,494	737,240	42.61
MOUNTRAIL	2,731	5,969	138,198	30,750	174,917	64.05
NELSON	3,219	21,343	138,566	36,249	196,158	60.93
OLIVER	1,738	1,738	137,815	19,571	159,124	91.55
PEMBINA	6,744	59,976	296,618	63,729	420,323	62.33
PIERCE	3,688	16,877	138,163	41,526	196,566	53.30
RAMSEY	9,255	38,363	289,408	87,459	415,230	44.87
RANSOM	4,322	14,024	139,096	48,669	201,789	46.69
RENVILLE	2,307	12,627	138,620	25,975	177,221	76.83
RICHLAND	13,183	68,403	295,206	124,580	488,189	37.03
ROLETTE	9,324	48,641	288,601	88,108	425,350	45.62
SARGENT	3,386	13,534	139,084	38,124	190,741	56.34
SHERIDAN	1,568	10,417	137,966	17,656	166,039	105.89
SIOUX	2,746	19,336	137,204	30,915	187,455	68.28
SLOPE	662	6,115	137,831	7,455	151,401	228.66
STARK	16,667	45,663	288,316	157,507	491,485	29.49
STEELE	1,767	7,483	139,407	19,892	166,781	94.41
STUTSMAN	16,236	56,271	289,026	153,430	498,727	30.72
TOWNER	2,648	8,005	138,482	29,813	176,300	66.59
TRAILL	6,389	40,756	295,718	60,376	396,849	62.11
WALSH	10,103	74,317	293,336	95,475	463,128	45.84
WARD	42,252	136,275	460,351	274,641	871,267	20.62
WELLS	4,281	22,937	138,507	48,201	209,645	48.97
WILLIAMS	15,424	80,720	288,337	145,758	514,816	33.38
FORT BERTHOLD	3,938	3,938	138,198	44,346	186,483	47.35
STATE TOTAL	466,325	2,040,695	10,908,064	3,933,550	16,882,309	36.20

APPENDIX TABLE C2. SCENARIO A2, COUNTY-LEVEL WASTE DISPOSAL COSTS UNDER BASELINE SCENARIO WITH ONE-HALF WASTE COLLECTION FROM RURAL POPULATION, NORTH DAKOTA, 1992

County	MSW	Costs of Disposal				Average Cost
		Transport.	Fixed	Variable	Total	
	- tons/year -	dollars				- $/ton -
ADAMS	1,847	4,010	137,649	20,792	162,450	87.98
BARNES	7,679	23,673	289,997	72,562	386,232	50.30
BENSON	4,650	51,763	138,315	52,359	242,437	52.14
BILLINGS	441	441	137,768	4,969	143,178	324.45
BOTTINEAU	4,484	29,103	138,513	50,485	218,101	48.64
BOWMAN	2,131	4,615	137,742	23,997	166,354	78.06
BURKE	1,720	13,601	137,578	19,366	170,545	99.16
BURLEIGH	40,498	63,037	457,412	263,239	783,688	19.35
CASS	71,796	145,585	631,313	425,031	1,201,929	16.74
CAVALIER	3,436	13,967	139,433	38,694	192,093	55.90
DICKEY	3,588	23,860	138,142	40,401	202,402	56.41
DIVIDE	1,648	22,168	138,021	18,556	178,745	108.46
DUNN	1,797	7,186	137,703	20,229	165,118	91.91
EDDY	1,715	1,715	138,373	19,312	159,400	92.94
EMMONS	2,627	11,589	137,847	29,582	179,018	68.14
FOSTER	2,355	6,067	138,685	26,521	171,273	72.72
GOLDEN VALLEY	1,275	2,541	138,109	14,355	155,005	121.58
GRAND FORKS	45,633	106,362	465,458	296,613	868,432	19.03
GRANT	1,849	8,842	137,578	20,820	167,240	90.45
GRIGGS	1,820	4,043	138,648	20,495	163,187	89.65
HETTINGER	1,969	12,902	138,087	22,173	173,162	87.94
KIDDER	1,734	8,901	137,503	19,526	165,929	95.69
LAMOURE	2,916	29,808	138,473	32,831	201,112	68.98
LOGAN	1,583	11,596	137,953	17,825	167,373	105.73
MCHENRY	3,517	34,442	138,053	39,596	212,091	60.31
MCINTOSH	2,416	16,323	137,809	27,199	181,331	75.07
MCKENZIE	2,788	10,869	137,970	31,392	180,230	64.65
MCLEAN	5,796	32,643	138,716	65,261	236,619	40.83
MERCER	6,271	22,439	288,435	59,261	370,135	59.02
MORTON	15,343	260,718	287,849	144,989	693,556	45.20
MOUNTRAIL	2,020	3,935	138,198	22,744	164,877	81.63
NELSON	2,607	16,851	138,566	29,357	184,774	70.87
OLIVER	1,171	1,171	137,815	13,181	152,167	129.99
PEMBINA	5,440	47,864	142,707	61,254	251,825	46.29
PIERCE	2,964	10,035	138,163	33,374	181,572	61.26
RAMSEY	7,841	26,445	289,408	74,097	389,950	49.73
RANSOM	3,420	10,715	139,096	38,510	188,321	55.06
RENVILLE	1,795	9,147	138,620	20,216	167,983	93.56
RICHLAND	11,229	51,387	295,206	106,116	452,709	40.32
ROLETTE	6,555	36,288	288,601	61,942	386,831	59.02
SARGENT	2,570	10,414	139,084	28,934	178,431	69.44
SHERIDAN	1,055	6,008	137,966	11,877	155,851	147.75
SIOUX	1,562	10,664	137,204	17,582	165,451	105.96
SLOPE	384	4,130	137,831	4,319	146,280	381.33
STARK	15,020	35,330	288,316	141,937	465,583	31.00
STEELE	1,242	5,308	139,407	13,989	158,705	127.74
STUTSMAN	14,253	38,551	289,026	134,687	462,264	32.43
TOWNER	2,117	5,516	138,482	23,833	167,831	79.29
TRAILL	5,286	30,833	142,196	59,515	232,543	44.00
WALSH	8,280	59,825	293,336	78,246	431,407	52.10
WARD	35,433	100,631	460,351	230,313	791,294	22.33
WELLS	3,398	18,085	138,507	38,264	194,856	57.34
WILLIAMS	13,429	64,011	288,337	126,900	479,250	35.69
FORT BERTHOLD	2,820	2,820	138,198	31,753	172,771	61.27
STATE TOTAL	399,208	1,590,771	10,449,753	3,341,370	15,381,894	38.53

APPENDIX TABLE C3. SCENARIO B, COUNTY-LEVEL WASTE DISPOSAL COSTS UNDER OPTIMUM SIZE AND LOCATION SCENARIO, NORTH DAKOTA, 1992

County	MSW	Costs of Disposal				Average Cost
		Transport.	Fixed	Variable	Total	
	- tons/year -	dollars				- $/ton -
ADAMS	2,317	60,184	15,061	27,459	102,704	44.33
BARNES	9,158	135,994	59,526	92,087	287,607	31.41
BENSON	5,351	54,298	50,566	66,179	171,043	31.97
BILLINGS	809	11,000	5,257	9,585	25,843	31.95
BOTTINEAU	5,848	130,703	49,103	68,738	248,544	42.50
BOWMAN	2,625	77,847	17,063	31,109	126,019	48.01
BURKE	2,191	82,534	20,709	27,003	130,247	59.43
BURLEIGH	43,896	82,927	259,862	348,303	691,093	15.74
CASS	75,098	174,721	444,580	607,828	1,227,130	16.34
CAVALIER	4,427	102,552	41,833	59,426	203,810	46.04
DICKEY	4,458	135,089	28,978	44,829	208,895	46.86
DIVIDE	2,116	53,697	19,999	26,077	99,773	47.15
DUNN	2,664	47,107	17,314	31,567	95,989	36.04
EDDY	2,061	32,973	19,475	25,488	77,935	37.82
EMMONS	3,526	89,249	20,873	27,977	138,099	39.17
FOSTER	2,908	50,524	18,899	29,237	98,660	33.93
GOLDEN VALLEY	1,539	38,205	10,002	18,236	66,444	43.18
GRAND FORKS	51,599	143,413	305,464	418,186	867,062	16.80
GRANT	2,591	77,792	16,261	26,795	120,848	46.65
GRIGGS	2,411	63,736	15,673	24,246	103,655	42.99
HETTINGER	2,515	45,579	16,347	29,803	91,729	36.47
KIDDER	2,432	48,157	14,850	20,946	83,953	34.51
LAMOURE	3,930	69,137	25,542	39,514	134,193	34.15
LOGAN	2,078	48,484	13,509	20,898	82,891	39.88
MCHENRY	4,765	99,260	30,976	40,179	170,415	35.76
MCINTOSH	2,935	106,675	18,800	28,493	153,967	52.45
MCKENZIE	4,020	70,357	36,665	49,324	156,346	38.89
MCLEAN	7,058	157,948	42,103	56,279	256,330	36.32
MERCER	7,120	212,409	45,067	76,174	333,650	46.86
MORTON	17,301	120,329	103,446	144,200	367,976	21.27
MOUNTRAIL	2,731	65,494	18,037	23,403	106,934	39.16
NELSON	3,219	71,699	19,058	26,091	116,849	36.30
OLIVER	1,738	28,505	10,290	13,792	52,587	30.25
PEMBINA	6,744	193,169	39,923	54,655	287,748	42.67
PIERCE	3,688	86,736	34,851	50,155	171,743	46.57
RAMSEY	9,255	38,363	87,459	114,465	240,287	25.96
RANSOM	4,322	105,194	34,504	53,590	193,289	44.72
RENVILLE	2,307	35,974	14,994	19,449	70,418	30.53
RICHLAND	13,183	68,403	124,580	203,813	396,796	30.10
ROLETTE	9,324	48,641	88,108	126,798	263,547	28.27
SARGENT	3,386	77,854	31,995	52,345	162,194	47.90
SHERIDAN	1,568	48,105	9,286	12,445	69,835	44.54
SIOUX	2,746	19,336	30,915	137,204	187,455	68.28
SLOPE	662	19,088	4,304	7,847	31,238	47.18
STARK	16,667	45,663	108,338	197,522	351,522	21.09
STEELE	1,767	47,885	10,458	14,311	72,654	41.13
STUTSMAN	16,236	56,271	105,534	163,261	325,065	20.02
TOWNER	2,648	32,625	25,021	33,551	91,197	34.44
TRAILL	6,389	110,659	37,823	51,775	200,256	31.34
WALSH	10,103	204,908	63,576	86,429	354,913	35.13
WARD	42,252	136,275	274,641	356,243	767,158	18.16
WELLS	4,281	122,592	36,800	50,081	209,473	48.93
WILLIAMS	15,424	80,720	145,758	190,058	416,537	27.01
FORT BERTHOLD	3,938	3,938	44,346	138,198	186,483	47.35
STATE TOTAL	466,325	4,370,980	3,184,404	4,693,646	12,249,030	26.27

APPENDIX TABLE C4. SCENARIO C, COUNTY-LEVEL WASTE DISPOSAL COSTS UNDER SCENARIO B WITH ONE-THIRD LESS WASTE COLLECTION, NORTH DAKOTA, 1992

County	MSW	Costs of Disposal				Average
		Transport.	Fixed	Variable	Total	Cost
	- tons/year -	dollars				- $/ton -
ADAMS	1,622	42,128	10,542	28,492	81,163	50.04
BARNES	6,411	95,198	41,669	94,719	231,585	36.13
BENSON	3,746	38,007	35,396	55,151	128,555	34.32
BILLINGS	566	7,700	3,680	9,947	21,327	37.67
BOTTINEAU	4,094	91,493	34,373	70,472	196,338	47.96
BOWMAN	1,838	54,494	11,944	32,282	98,720	53.72
BURKE	1,534	52,143	9,971	16,772	78,886	51.43
BURLEIGH	30,727	58,049	181,903	351,657	591,609	19.25
CASS	52,569	122,306	311,207	564,509	998,021	18.99
CAVALIER	3,099	71,616	29,284	58,942	159,841	51.58
DICKEY	3,121	94,560	20,284	46,108	160,952	51.58
DIVIDE	1,481	37,587	13,999	28,904	80,490	54.33
DUNN	1,865	32,975	12,120	32,756	77,851	41.75
EDDY	1,443	23,082	13,633	21,241	57,955	40.17
EMMONS	2,468	62,473	14,611	28,246	105,331	42.68
FOSTER	2,035	35,367	13,229	30,072	78,668	38.65
GOLDEN VALLEY	1,077	26,744	7,002	18,923	52,669	48.89
GRAND FORKS	36,119	100,389	213,824	446,781	760,994	21.07
GRANT	1,814	54,454	11,383	27,582	93,418	51.51
GRIGGS	1,688	44,614	10,971	24,938	80,523	47.71
HETTINGER	1,760	31,906	11,443	30,925	74,274	42.19
KIDDER	1,703	33,711	10,395	21,296	65,402	38.41
LAMOURE	2,751	48,394	17,879	40,641	106,913	38.87
LOGAN	1,455	33,314	9,003	18,894	61,212	42.08
MCHENRY	3,336	69,481	21,683	36,472	127,636	38.26
MCINTOSH	2,055	74,675	13,160	29,235	117,070	56.97
MCKENZIE	2,814	49,249	25,665	54,293	129,208	45.92
MCLEAN	4,941	91,311	30,651	55,311	177,272	35.88
MERCER	4,984	143,190	30,978	72,568	246,736	49.50
MORTON	12,111	84,231	72,412	146,175	302,818	25.00
MOUNTRAIL	1,912	45,410	12,425	20,901	78,736	41.19
NELSON	2,253	39,321	21,291	33,174	93,785	41.63
OLIVER	1,217	19,954	7,203	13,925	41,081	33.76
PEMBINA	4,721	135,218	27,946	58,392	221,556	46.93
PIERCE	2,582	60,132	24,395	50,551	135,079	52.33
RAMSEY	6,478	26,853	61,221	95,390	183,464	28.32
RANSOM	3,026	77,881	17,912	32,491	128,285	42.40
RENVILLE	1,615	25,183	10,496	17,656	53,335	33.03
RICHLAND	9,228	48,361	82,982	240,794	372,137	40.33
ROLETTE	6,527	34,050	61,676	135,129	230,855	35.37
SARGENT	2,370	54,497	22,396	67,264	144,157	60.83
SHERIDAN	1,098	29,679	6,645	12,433	48,758	44.42
SIOUX	1,922	13,535	21,641	137,204	172,380	89.69
SLOPE	463	13,359	3,012	8,141	24,512	52.90
STARK	11,667	31,963	75,836	204,959	312,759	26.81
STEELE	1,237	33,519	7,321	14,585	55,424	44.82
STUTSMAN	11,365	39,390	73,874	167,924	281,188	24.74
TOWNER	1,853	22,838	17,515	30,025	70,377	37.97
TRAILL	4,472	73,541	26,475	52,772	152,788	34.16
WALSH	7,072	143,435	44,503	89,239	277,177	39.19
WARD	29,577	95,393	192,249	323,380	611,021	20.66
WELLS	2,996	85,218	26,074	44,160	155,452	51.88
WILLIAMS	10,797	56,506	102,032	210,661	369,199	34.19
FORT BERTHOLD	2,757	2,757	31,042	138,198	171,996	62.39
STATE TOTAL	326,427	3,012,832	2,222,455	4,693,654	9,928,941	30.42

APPENDIX TABLE C5. SCENARIO D1, COUNTY-LEVEL WASTE DISPOSAL COSTS WITH TRANSFER STATIONS OPERATING WITH 50 MILE BREAK-EVEN DISTANCE AND 12 TONS PER DAY CAPACITY, NORTH DAKOTA, 1992

County	MSW	Costs of Disposal				Average Cost
		Transport.	Fixed	Variable	Total	
	- tons/year -	dollars				- $/ton -
ADAMS	2,317	33,597	18,459	27,613	79,670	34.38
BARNES	9,158	89,478	102,178	76,985	268,641	29.33
BENSON	5,351	43,880	37,055	45,044	125,979	23.54
BILLINGS	809	11,728	3,268	9,639	24,635	30.46
BOTTINEAU	5,848	76,358	79,625	49,257	205,240	35.10
BOWMAN	2,625	38,064	21,912	31,284	91,260	34.76
BURKE	2,191	38,241	34,207	27,116	99,563	45.43
BURLEIGH	43,896	259,862	82,927	348,304	691,093	15.74
CASS	75,098	451,050	168,689	608,061	1,227,800	16.35
CAVALIER	4,427	49,144	56,928	37,264	143,336	32.38
DICKEY	4,458	66,749	51,702	43,671	162,123	36.37
DIVIDE	2,116	24,041	46,462	26,186	96,689	45.69
DUNN	2,664	30,326	25,248	31,745	87,319	32.78
EDDY	2,061	29,882	8,985	17,348	56,215	27.28
EMMONS	3,526	43,246	38,622	27,977	109,846	31.15
FOSTER	2,908	37,027	21,792	24,442	83,261	28.64
GOLDEN VALLEY	1,539	22,313	11,160	18,339	51,813	33.67
GRAND FORKS	51,599	359,803	144,468	439,545	943,816	18.29
GRANT	2,591	37,566	29,423	30,875	97,865	37.77
GRIGGS	2,411	34,962	19,056	20,269	74,288	30.81
HETTINGER	2,515	26,169	24,313	29,971	80,453	31.99
KIDDER	2,432	31,518	23,213	19,449	74,181	30.50
LAMOURE	3,930	25,542	69,137	33,034	127,713	32.50
LOGAN	2,078	22,292	23,027	17,357	62,675	30.16
MCHENRY	4,765	45,161	76,716	40,171	162,048	34.00
MCINTOSH	2,935	42,282	37,305	24,448	104,036	35.44
MCKENZIE	4,020	57,677	34,800	49,537	142,014	35.33
MCLEAN	7,058	72,381	87,483	56,558	216,423	30.66
MERCER	7,120	101,965	75,954	76,060	253,979	35.67
MORTON	17,301	116,946	97,637	139,933	354,516	20.49
MOUNTRAIL	2,731	39,599	17,985	23,026	80,609	29.52
NELSON	3,219	20,925	56,188	27,100	104,213	32.37
OLIVER	1,738	22,568	10,026	13,792	46,386	26.69
PEMBINA	6,744	87,039	112,105	56,913	256,056	37.97
PIERCE	3,688	53,475	30,322	31,045	114,842	31.14
RAMSEY	9,255	60,157	38,363	77,909	176,429	19.06
RANSOM	4,322	57,712	47,906	36,154	141,772	32.80
RENVILLE	2,307	27,287	14,523	19,449	61,260	26.56
RICHLAND	13,183	124,580	68,403	225,177	418,160	31.72
ROLETTE	9,324	114,974	77,681	164,110	356,765	38.26
SARGENT	3,386	59,082	29,785	57,831	146,698	43.33
SHERIDAN	1,568	22,037	17,068	12,615	51,721	32.98
SIOUX	2,746	30,915	19,336	137,204	187,455	68.28
SLOPE	662	9,601	6,688	7,891	24,179	36.52
STARK	16,667	108,338	45,663	198,633	352,633	21.16
STEELE	1,767	25,616	18,789	14,851	59,255	33.54
STUTSMAN	16,236	105,534	56,271	136,486	298,291	18.37
TOWNER	2,648	22,942	35,347	22,288	80,577	30.43
TRAILL	6,389	73,002	69,710	52,751	195,462	30.59
WALSH	10,103	91,952	162,813	85,552	340,318	33.68
WARD	42,252	274,641	136,275	356,244	767,160	18.16
WELLS	4,281	62,071	45,898	36,009	143,978	33.63
WILLIAMS	15,424	145,758	80,720	190,849	417,328	27.06
FORT BERTHOLD	3,938	44,346	3,938	138,198	186,483	47.35
STATE TOTAL	466,325	4,003,404	2,753,557	4,549,560	11,306,521	24.25

APPENDIX TABLE C6. SCENARIO D2, COUNTY-LEVEL WASTE DISPOSAL COSTS WITH TRANSFER STATIONS OPERATING WITH 75 MILE BREAK-EVEN DISTANCE AND 12 TONS PER DAY CAPACITY, NORTH DAKOTA, 1992

County	MSW	Costs of Disposal				Average Cost
		Transport.	Fixed	Variable	Total	
	- tons/year -	dollars				- $/ton -
ADAMS	2,317	36,313	23,701	28,559	88,573	38.23
BARNES	9,158	59,526	135,994	76,985	272,505	29.76
BENSON	5,351	48,429	37,055	45,044	130,528	24.39
BILLINGS	809	5,257	11,000	9,969	26,227	32.43
BOTTINEAU	5,848	95,531	79,648	49,257	224,436	38.38
BOWMAN	2,625	48,564	21,912	32,356	102,832	39.17
BURKE	2,191	47,007	34,207	27,003	108,217	49.38
BURLEIGH	43,896	259,862	82,927	348,304	691,093	15.74
CASS	75,098	460,648	175,169	616,573	1,252,390	16.68
CAVALIER	4,427	59,329	56,928	37,264	153,521	34.68
DICKEY	4,458	84,281	50,449	51,810	186,541	41.84
DIVIDE	2,116	26,061	46,462	26,077	98,601	46.59
DUNN	2,664	36,832	25,248	32,832	94,912	35.63
EDDY	2,061	13,395	32,973	17,348	63,716	30.92
EMMONS	3,526	54,433	38,622	27,977	121,033	34.33
FOSTER	2,908	46,090	21,792	24,442	92,325	31.75
GOLDEN VALLEY	1,539	26,524	12,872	18,967	58,363	37.93
GRAND FORKS	51,599	372,009	144,468	439,545	956,023	18.53
GRANT	2,591	35,376	40,201	27,551	103,128	39.81
GRIGGS	2,411	44,607	19,056	20,269	83,933	34.81
HETTINGER	2,515	31,081	24,313	30,997	86,391	34.35
KIDDER	2,432	34,726	27,488	19,666	81,880	33.66
LAMOURE	3,930	25,542	69,137	33,034	127,713	32.50
LOGAN	2,078	26,722	23,031	17,331	67,084	32.28
MCHENRY	4,765	52,254	79,379	40,156	171,789	36.05
MCINTOSH	2,935	54,024	37,305	24,448	115,777	39.44
MCKENZIE	4,020	68,183	34,800	49,537	152,520	37.94
MCLEAN	7,058	77,463	91,642	56,988	226,094	32.03
MERCER	7,120	129,650	73,619	72,026	275,294	38.66
MORTON	17,301	124,654	97,637	145,039	367,330	21.23
MOUNTRAIL	2,731	50,809	18,425	23,403	92,637	33.92
NELSON	3,219	20,925	56,188	27,100	104,213	32.37
OLIVER	1,738	14,700	24,080	13,792	52,572	30.25
PEMBINA	6,744	108,641	112,105	56,913	277,658	41.17
PIERCE	3,688	68,227	30,322	31,045	129,594	35.14
RAMSEY	9,255	60,157	38,363	77,909	176,429	19.06
RANSOM	4,322	72,688	47,906	36,154	156,748	36.26
RENVILLE	2,307	33,434	14,523	19,449	67,406	29.22
RICHLAND	13,183	124,580	68,403	210,841	403,824	30.63
ROLETTE	9,324	101,446	101,992	164,110	367,548	39.42
SARGENT	3,386	48,718	51,301	54,150	154,169	45.53
SHERIDAN	1,568	24,111	19,456	12,622	56,188	35.83
SIOUX	2,746	30,915	19,336	137,204	187,455	68.28
SLOPE	662	12,249	6,688	8,161	27,098	40.93
STARK	16,667	108,338	45,663	205,436	359,436	21.57
STEELE	1,767	26,101	12,309	6,339	44,749	25.33
STUTSMAN	16,236	105,534	56,271	136,486	298,291	18.37
TOWNER	2,648	17,210	43,601	22,288	83,100	31.39
TRAILL	6,389	84,671	73,579	52,746	210,996	33.03
WALSH	10,103	105,093	162,813	85,552	353,458	34.98
WARD	42,252	274,641	136,275	356,244	767,160	18.16
WELLS	4,281	79,194	46,009	36,003	161,206	37.66
WILLIAMS	15,424	145,758	80,720	190,058	416,537	27.01
FORT BERTHOLD	3,938	44,346	3,938	138,198	186,483	47.35
STATE TOTAL	466,325	4,246,861	2,919,302	4,549,560	11,715,723	25.12

APPENDIX TABLE C7. SCENARIO D3, COUNTY-LEVEL WASTE DISPOSAL COSTS WITH TRANSFER STATIONS OPERATING WITH 50 MILE BREAK-EVEN DISTANCE AND 18 TONS PER DAY CAPACITY, NORTH DAKOTA, 1992

County	MSW	Costs of Disposal				Average Cost
		Transport.	Fixed	Variable	Total	
	- tons/year -	dollars				- $/ton -
ADAMS	2,317	33,597	18,459	27,385	79,442	34.29
BARNES	9,158	104,454	85,480	79,152	269,086	29.38
BENSON	5,351	43,880	37,055	45,044	125,979	23.54
BILLINGS	809	11,728	3,268	9,560	24,556	30.36
BOTTINEAU	5,848	76,358	79,490	49,257	205,106	35.07
BOWMAN	2,625	38,064	21,912	31,026	91,002	34.67
BURKE	2,191	38,241	34,207	27,116	99,563	45.43
BURLEIGH	43,896	259,862	82,927	348,304	691,093	15.74
CASS	75,098	451,050	168,689	608,240	1,227,979	16.35
CAVALIER	4,427	59,259	44,645	37,264	141,168	31.89
DICKEY	4,458	70,216	47,335	52,418	169,969	38.13
DIVIDE	2,116	24,041	46,462	26,186	96,689	45.69
DUNN	2,664	30,326	25,248	31,483	87,057	32.68
EDDY	2,061	29,882	8,985	17,348	56,215	27.28
EMMONS	3,526	43,246	38,622	27,977	109,846	31.15
FOSTER	2,908	37,027	21,792	25,131	83,949	28.87
GOLDEN VALLEY	1,539	22,313	11,160	18,188	51,661	33.57
GRAND FORKS	51,599	357,776	143,637	439,572	940,984	18.24
GRANT	2,591	37,566	29,423	30,620	97,610	37.68
GRIGGS	2,411	34,962	19,056	20,840	74,858	31.05
HETTINGER	2,515	26,169	24,313	29,723	80,205	31.89
KIDDER	2,432	31,518	23,213	19,524	74,255	30.53
LAMOURE	3,930	25,542	69,137	33,964	128,643	32.74
LOGAN	2,078	22,433	23,007	17,963	63,403	30.51
MCHENRY	4,765	45,161	75,343	40,178	160,683	33.72
MCINTOSH	2,935	42,282	37,305	25,029	104,616	35.64
MCKENZIE	4,020	57,677	34,800	49,493	141,970	35.32
MCLEAN	7,058	76,553	84,785	56,279	217,617	30.83
MERCER	7,120	101,512	66,580	72,542	240,635	33.79
MORTON	17,301	117,585	97,637	144,144	359,366	20.77
MOUNTRAIL	2,731	39,599	17,986	23,026	80,610	29.52
NELSON	3,219	20,925	56,188	27,100	104,213	32.37
OLIVER	1,738	24,195	7,578	13,792	45,565	26.21
PEMBINA	6,744	87,039	112,658	56,913	256,610	38.05
PIERCE	3,688	53,475	30,322	31,045	114,842	31.14
RAMSEY	9,255	60,157	38,363	77,909	176,429	19.06
RANSOM	4,322	62,674	42,724	37,358	142,756	33.03
RENVILLE	2,307	27,287	14,523	19,449	61,260	26.56
RICHLAND	13,183	124,580	68,403	210,841	403,824	30.63
ROLETTE	9,324	114,974	73,104	164,110	352,187	37.77
SARGENT	3,386	59,082	29,785	54,150	143,016	42.24
SHERIDAN	1,568	22,037	16,992	12,635	51,664	32.95
SIOUX	2,746	30,915	19,336	137,204	187,455	68.28
SLOPE	662	9,601	6,688	7,826	24,114	36.42
STARK	16,667	108,338	45,663	196,993	350,993	21.06
STEELE	1,767	25,616	18,789	15,269	59,673	33.78
STUTSMAN	16,236	105,534	56,271	140,329	302,133	18.61
TOWNER	2,648	38,392	16,266	22,288	76,946	29.06
TRAILL	6,389	72,667	64,265	53,212	190,143	29.76
WALSH	10,103	110,599	137,028	85,525	333,152	32.97
WARD	42,252	274,641	136,275	356,244	767,160	18.16
WELLS	4,281	62,071	44,434	36,348	142,853	33.37
WILLIAMS	15,424	145,758	80,720	190,849	417,328	27.06
FORT BERTHOLD	3,938	44,346	3,938	138,198	186,483	47.35
STATE TOTAL	466,325	4,074,782	2,642,273	4,549,560	11,266,615	24.16

APPENDIX TABLE C8. SCENARIO D4, COUNTY-LEVEL WASTE DISPOSAL COSTS WITH TRANSFER STATIONS OPERATING WITH 75 MILE BREAK-EVEN DISTANCE AND 18 TONS PER DAY CAPACITY, NORTH DAKOTA, 1992

County	MSW	Costs of Disposal				Average
		Transport.	Fixed	Variable	Total	Cost
	- tons/year -	dollars				- $/ton -
ADAMS	2,317	36,313	23,701	28,559	88,573	38.23
BARNES	9,158	59,526	135,994	76,985	272,505	29.76
BENSON	5,351	48,429	37,055	45,044	130,528	24.39
BILLINGS	809	5,257	11,000	9,969	26,227	32.43
BOTTINEAU	5,848	95,531	79,490	49,257	224,278	38.35
BOWMAN	2,625	48,564	21,912	32,356	102,832	39.17
BURKE	2,191	47,007	34,207	27,003	108,217	49.38
BURLEIGH	43,896	259,862	82,927	348,304	691,093	15.74
CASS	75,098	454,067	168,689	608,061	1,230,817	16.39
CAVALIER	4,427	59,329	56,928	37,264	153,521	34.68
DICKEY	4,458	66,428	41,381	21,595	129,404	29.03
DIVIDE	2,116	26,061	46,462	26,077	98,601	46.59
DUNN	2,664	36,832	25,248	32,832	94,912	35.63
EDDY	2,061	13,395	32,973	17,348	63,716	30.92
EMMONS	3,526	54,433	38,622	27,977	121,033	34.33
FOSTER	2,908	46,090	21,792	24,442	92,325	31.75
GOLDEN VALLEY	1,539	26,524	12,872	18,967	58,363	37.93
GRAND FORKS	51,599	344,040	143,470	439,794	927,305	17.97
GRANT	2,591	35,376	40,201	27,551	103,128	39.81
GRIGGS	2,411	44,607	19,056	20,269	83,933	34.81
HETTINGER	2,515	31,081	24,313	30,997	86,391	34.35
KIDDER	2,432	34,726	27,488	19,666	81,880	33.66
LAMOURE	3,930	25,542	69,137	33,034	127,713	32.50
LOGAN	2,078	26,519	23,059	17,166	66,744	32.11
MCHENRY	4,765	52,254	79,379	40,156	171,789	36.05
MCINTOSH	2,935	54,024	37,305	24,448	115,777	39.44
MCKENZIE	4,020	68,183	34,800	49,537	152,520	37.94
MCLEAN	7,058	73,468	93,321	57,162	223,951	31.73
MERCER	7,120	129,650	66,580	72,026	268,256	37.67
MORTON	17,301	124,654	97,637	145,039	367,330	21.23
MOUNTRAIL	2,731	50,809	18,117	23,403	92,328	33.81
NELSON	3,219	20,925	56,188	27,100	104,213	32.37
OLIVER	1,738	31,147	7,578	13,792	52,517	30.21
PEMBINA	6,744	108,641	112,658	56,913	278,212	41.25
PIERCE	3,688	68,227	30,322	31,045	129,594	35.14
RAMSEY	9,255	60,157	38,363	77,909	176,429	19.06
RANSOM	4,322	79,963	42,724	36,335	159,022	36.79
RENVILLE	2,307	33,434	14,523	19,449	67,406	29.22
RICHLAND	13,183	124,580	68,403	210,841	403,824	30.63
ROLETTE	9,324	127,309	73,104	164,110	364,522	39.10
SARGENT	3,386	66,571	60,369	84,365	211,306	62.41
SHERIDAN	1,568	28,309	17,158	12,614	58,082	37.04
SIOUX	2,746	30,915	19,336	137,204	187,455	68.28
SLOPE	662	12,249	6,688	8,161	27,098	40.93
STARK	16,667	108,338	45,663	205,436	359,436	21.57
STEELE	1,767	32,682	18,789	14,851	66,322	37.54
STUTSMAN	16,236	105,534	56,271	136,486	298,291	18.37
TOWNER	2,648	17,210	43,601	22,288	83,100	31.39
TRAILL	6,389	89,296	64,265	52,565	206,126	32.26
WALSH	10,103	133,063	155,727	85,303	374,093	37.03
WARD	42,252	274,641	136,275	356,244	767,160	18.16
WELLS	4,281	79,194	46,151	36,002	161,346	37.69
WILLIAMS	15,424	145,758	80,720	190,058	416,537	27.01
FORT BERTHOLD	3,938	44,346	3,938	138,198	186,483	47.35
STATE TOTAL	466,325	4,301,071	2,843,934	4,549,560	11,694,565	25.08

APPENDIX TABLE C9. SCENARIO E, COUNTY-LEVEL WASTE DISPOSAL COSTS WITH WASTE INCINERATOR LOCATED AT GRAFTON, NORTH DAKOTA, 1992

County	MSW	Costs of Disposal				Average Cost
		Transport.	Fixed	Variable	Total	
	- tons/year -	dollars				- $/ton -
ADAMS	2,317	15,061	60,184	27,459	102,704	44.33
BARNES	9,158	59,526	135,994	86,871	282,391	30.84
BENSON	5,351	50,566	54,298	66,179	171,042	31.97
BILLINGS	809	5,257	11,000	9,585	25,843	31.95
BOTTINEAU	5,848	49,103	130,703	77,459	257,265	43.99
BOWMAN	2,625	17,063	77,847	31,109	126,019	48.01
BURKE	2,191	20,709	82,534	27,003	130,247	59.43
BURLEIGH	43,896	259,862	82,927	348,304	691,093	15.74
CASS	75,098	444,580	174,721	607,825	1,227,127	16.34
CAVALIER	4,427	41,833	93,669	59,724	195,225	44.10
DICKEY	4,458	28,978	135,089	42,289	206,356	46.29
DIVIDE	2,116	19,999	53,697	26,077	99,773	47.15
DUNN	2,664	17,314	47,107	31,568	95,989	36.04
EDDY	2,061	19,475	32,973	25,488	77,935	37.82
EMMONS	3,526	20,873	89,249	27,977	138,099	39.17
FOSTER	2,908	18,899	50,524	27,581	97,004	33.36
GOLDEN VALLEY	1,539	10,002	38,205	18,237	66,444	43.18
GRAND FORKS	51,599	338,801	139,863	444,508	923,171	17.89
GRANT	2,591	16,261	77,792	26,795	120,848	46.65
GRIGGS	2,411	15,673	63,736	22,872	102,281	42.42
HETTINGER	2,515	16,347	45,579	29,803	91,729	36.47
KIDDER	2,432	14,850	48,157	20,504	83,511	34.33
LAMOURE	3,930	25,542	69,137	37,276	131,955	33.58
LOGAN	2,078	13,509	48,484	19,715	81,708	39.31
MCHENRY	4,765	30,976	99,260	40,180	170,415	35.76
MCINTOSH	2,935	18,800	106,675	27,096	152,570	51.98
MCKENZIE	4,020	36,665	70,357	49,324	156,346	38.89
MCLEAN	7,058	42,103	157,948	56,279	256,330	36.32
MERCER	7,120	45,067	212,409	76,174	333,650	46.86
MORTON	17,301	103,446	120,329	144,200	367,976	21.27
MOUNTRAIL	2,731	18,037	65,494	23,403	106,934	39.16
NELSON	3,219	30,422	60,547	40,045	131,014	40.70
OLIVER	1,738	10,290	28,505	13,792	52,587	30.25
PEMBINA	6,744	63,729	103,716	84,538	251,983	37.37
PIERCE	3,688	34,851	86,081	56,771	177,703	48.18
RAMSEY	9,255	87,459	35,959	114,608	238,027	25.72
RANSOM	4,322	35,157	113,303	55,158	203,618	47.11
RENVILLE	2,307	14,994	35,974	19,449	70,418	30.53
RICHLAND	13,183	124,580	68,403	203,812	396,796	30.10
ROLETTE	9,324	88,108	48,641	148,426	285,175	30.59
SARGENT	3,386	31,995	77,854	52,344	162,194	47.90
SHERIDAN	1,568	9,286	48,105	12,445	69,835	44.54
SIOUX	2,746	30,915	19,336	137,204	187,455	68.28
SLOPE	662	4,304	19,088	7,847	31,238	47.18
STARK	16,667	108,338	45,663	197,522	351,523	21.09
STEELE	1,767	11,483	57,903	16,758	86,144	48.76
STUTSMAN	16,236	105,534	56,271	154,013	315,818	19.45
TOWNER	2,648	25,021	32,625	35,067	92,713	35.02
TRAILL	6,389	40,234	105,060	53,503	198,797	31.12
WALSH	10,103	95,475	74,317	126,651	296,443	29.34
WARD	42,252	274,641	136,275	356,244	767,160	18.16
WELLS	4,281	37,249	121,741	49,813	208,803	48.78
WILLIAMS	15,424	145,758	80,720	190,058	416,537	27.01
FORT BERTHOLD	3,938	44,346	3,938	138,198	186,483	47.35
STATE TOTAL	466,325	3,289,347	4,135,968	4,823,129	12,248,444	26.27

APPENDIX TABLE C10. SCENARIO F, COUNTY-LEVEL WASTE DISPOSAL COSTS WITH FARGO-WEST FARGO, BISMARCK-MANDAN, AND MCKENZIE COUNTY RECEIVING WASTE ONLY FROM THEIR OWN JURISDICTION, NORTH DAKOTA, 1992

County	MSW	Costs of Disposal				Average Cost
		Transport.	Fixed	Variable	Total	
	- tons/year -	dollars				- $/ton -
ADAMS	2,317	15,061	60,184	24,661	99,905	43.12
BARNES	9,158	59,526	135,994	76,985	272,505	29.76
BENSON	5,351	50,566	54,298	66,179	171,042	31.97
BILLINGS	809	5,257	11,000	8,609	24,866	30.74
BOTTINEAU	5,848	39,822	171,358	54,520	265,700	45.43
BOWMAN	2,625	17,063	77,847	27,939	122,849	46.80
BURKE	2,191	20,709	82,534	27,891	131,135	59.84
BURLEIGH	43,896	308,741	126,338	447,403	882,481	20.10
CASS	75,098	451,119	393,915	795,948	1,640,983	21.85
CAVALIER	4,427	41,833	110,196	54,749	206,778	46.71
DICKEY	4,458	28,978	131,310	48,166	208,453	46.76
DIVIDE	2,116	19,999	53,697	26,934	100,630	47.55
DUNN	2,664	17,314	47,107	28,351	92,772	34.83
EDDY	2,061	13,395	48,635	17,324	79,354	38.51
EMMONS	3,526	28,302	140,687	36,766	205,755	58.36
FOSTER	2,908	18,899	50,524	24,442	93,866	32.28
GOLDEN VALLEY	1,539	10,002	38,205	16,378	64,585	41.97
GRAND FORKS	51,599	305,464	143,413	416,304	865,180	16.77
GRANT	2,591	16,840	90,566	27,574	134,980	52.10
GRIGGS	2,411	15,673	63,736	20,269	99,678	41.34
HETTINGER	2,515	16,347	45,579	26,766	88,692	35.27
KIDDER	2,432	17,449	50,318	22,616	90,384	37.16
LAMOURE	3,930	25,542	69,137	33,034	127,713	32.50
LOGAN	2,078	13,509	48,484	17,471	79,464	38.23
MCHENRY	4,765	30,976	99,260	40,180	170,415	35.76
MCINTOSH	2,935	19,080	110,149	24,676	153,904	52.43
MCKENZIE	4,020	45,266	18,508	137,970	201,744	50.18
MCLEAN	7,058	66,702	100,555	86,895	254,152	36.01
MERCER	7,120	51,365	198,752	78,657	328,774	46.17
MORTON	17,301	115,387	184,963	175,617	475,967	27.51
MOUNTRAIL	2,731	25,807	83,893	34,757	144,458	52.90
NELSON	3,219	19,058	71,699	25,974	116,731	36.26
OLIVER	1,738	16,425	29,201	21,398	67,024	38.56
PEMBINA	6,744	39,923	193,169	54,409	287,502	42.63
PIERCE	3,688	39,947	28,741	73,131	141,819	38.45
RAMSEY	9,255	87,459	38,363	114,464	240,287	25.96
RANSOM	4,322	28,095	118,129	56,890	203,114	46.99
RENVILLE	2,307	14,994	35,974	19,449	70,418	30.53
RICHLAND	13,183	85,690	68,403	185,410	339,503	25.75
ROLETTE	9,324	104,912	63,664	206,042	374,619	40.18
SARGENT	3,386	22,007	77,854	47,618	147,479	43.56
SHERIDAN	1,568	14,818	33,195	19,304	67,317	42.93
SIOUX	2,746	30,915	19,336	137,204	187,455	68.28
SLOPE	662	4,304	19,088	7,047	30,439	45.97
STARK	16,667	108,338	45,663	177,393	331,394	19.88
STEELE	1,767	11,483	57,903	14,851	84,237	47.68
STUTSMAN	16,236	105,534	56,271	136,486	298,291	18.37
TOWNER	2,648	25,021	43,601	32,747	101,369	38.29
TRAILL	6,389	37,823	112,201	51,547	201,571	31.55
WALSH	10,103	62,663	206,564	84,988	354,214	35.06
WARD	42,252	275,209	141,743	357,071	774,022	18.32
WELLS	4,281	27,825	142,331	35,986	206,142	48.16
WILLIAMS	15,424	145,758	80,720	196,305	422,783	27.41
FORT BERTHOLD	3,938	44,346	3,938	138,198	186,483	47.35
STATE TOTAL	466,325	3,264,541	4,728,895	5,119,941	13,113,377	28.12

APPENDIX TABLE C11. SCENARIO G, COUNTY-LEVEL WASTE DISPOSAL COSTS WITHOUT ELLENDALE, NORTH DAKOTA, 1992

County	MSW	Costs of Disposal				Average Cost
		Transport.	Fixed	Variable	Total	
	- tons/year -	dollars				- $/ton -
ADAMS	2,317	15,061	60,184	27,459	102,704	44.33
BARNES	9,158	59,526	135,994	95,724	291,244	31.80
BENSON	5,351	50,566	54,298	66,179	171,042	31.97
BILLINGS	809	5,257	11,000	9,585	25,843	31.95
BOTTINEAU	5,848	49,103	130,703	68,738	248,544	42.50
BOWMAN	2,625	17,063	77,847	31,109	126,019	48.01
BURKE	2,191	20,709	82,534	27,003	130,247	59.43
BURLEIGH	43,896	259,862	82,927	348,304	691,093	15.74
CASS	75,098	444,580	174,721	607,825	1,227,127	16.34
CAVALIER	4,427	41,833	102,552	59,426	203,810	46.04
DICKEY	2,724	17,704	89,298	28,469	135,471	49.74
DIVIDE	2,116	19,999	53,697	26,077	99,773	47.15
DUNN	2,664	17,314	47,107	31,568	95,989	36.04
EDDY	2,061	19,475	32,973	25,488	77,935	37.82
EMMONS	3,526	20,873	89,249	27,977	138,099	39.17
FOSTER	2,908	18,899	50,524	30,392	99,815	34.33
GOLDEN VALLEY	1,539	10,002	38,205	18,237	66,444	43.18
GRAND FORKS	51,599	305,464	143,413	418,188	867,064	16.80
GRANT	2,591	16,261	77,792	26,795	120,848	46.65
GRIGGS	2,411	15,673	63,736	25,203	104,612	43.39
HETTINGER	2,515	16,347	45,579	29,803	91,729	36.47
KIDDER	2,432	14,850	48,157	21,254	84,261	34.64
LAMOURE	3,930	25,542	69,137	41,075	135,754	34.55
LOGAN	2,078	13,509	48,484	21,724	83,717	40.28
MCHENRY	4,765	30,976	99,260	40,180	170,415	35.76
MCINTOSH	2,935	18,800	106,675	29,467	154,942	52.79
MCKENZIE	4,020	36,665	70,357	49,324	156,346	38.89
MCLEAN	7,058	42,103	157,948	56,279	256,330	36.32
MERCER	7,120	45,067	212,409	76,174	333,650	46.86
MORTON	17,301	103,446	120,329	144,200	367,976	21.27
MOUNTRAIL	2,731	18,037	65,494	23,403	106,934	39.16
NELSON	3,219	19,058	71,699	26,091	116,849	36.30
OLIVER	1,738	10,290	28,505	13,792	52,587	30.25
PEMBINA	6,744	39,923	193,169	54,656	287,748	42.67
PIERCE	3,688	34,851	86,736	50,155	171,743	46.57
RAMSEY	9,255	87,459	38,363	114,464	240,287	25.96
RANSOM	4,322	34,504	105,194	53,590	193,289	44.72
RENVILLE	2,307	14,994	35,974	19,449	70,418	30.53
RICHLAND	13,183	124,580	68,403	203,812	396,796	30.10
ROLETTE	9,324	88,108	48,641	126,798	263,547	28.27
SARGENT	3,386	31,995	77,854	52,344	162,194	47.90
SHERIDAN	1,568	9,286	48,105	12,445	69,835	44.54
SIOUX	2,746	30,915	19,336	137,204	187,455	68.28
SLOPE	662	4,304	19,088	7,847	31,238	47.18
STARK	16,667	108,338	45,663	197,522	351,523	21.09
STEELE	1,767	10,458	47,885	14,311	72,654	41.13
STUTSMAN	16,236	105,534	56,271	169,709	331,514	20.42
TOWNER	2,648	25,021	32,625	33,551	91,197	34.44
TRAILL	6,389	37,823	110,659	51,775	200,256	31.34
WALSH	10,103	63,576	204,908	86,430	354,914	35.13
WARD	42,252	274,641	136,275	356,244	767,160	18.16
WELLS	4,281	36,800	122,592	50,572	209,965	49.05
WILLIAMS	15,424	145,758	80,720	190,058	416,537	27.01
FORT BERTHOLD	3,938	44,346	3,938	138,198	186,483	47.35
STATE TOTAL	464,591	3,173,129	4,325,190	4,693,648	12,191,967	26.24

APPENDIX TABLE C12. SCENARIO H, COUNTY-LEVEL WASTE DISPOSAL COSTS WITH IMPORTS AND ASSUMPTIONS FROM SCENARIOS E, F, AND G, IN NORTH DAKOTA, 1992

County	MSW	Costs of Disposal				Average Cost
		Transport.	Fixed	Variable	Total	
	- tons/year -	dollars				- $/ton -
ADAMS	2,317	60,184	15,061	31,991	107,236	46.28
BARNES	9,158	131,918	59,526	100,039	291,483	31.83
BENSON	5,351	54,298	34,781	81,944	171,022	31.96
BILLINGS	809	11,000	5,257	11,168	27,425	33.91
BOTTINEAU	5,848	130,703	49,103	96,596	276,402	47.26
BOWMAN	2,625	77,847	17,063	36,244	131,154	49.96
BURKE	2,191	82,534	20,709	31,875	135,119	61.66
BURLEIGH	43,896	126,338	285,322	455,200	866,859	19.75
CASS	75,098	218,519	444,934	608,618	1,272,071	16.94
CAVALIER	4,427	94,183	38,144	72,563	204,890	46.28
DICKEY	2,724	35,474	17,704	25,183	78,361	28.77
DIVIDE	2,116	53,697	19,999	30,782	104,478	49.37
DUNN	2,664	47,107	17,314	36,778	101,200	37.99
EDDY	2,061	32,973	13,395	31,559	77,927	37.81
EMMONS	3,526	120,277	22,918	46,870	190,065	53.91
FOSTER	2,908	50,524	18,899	32,392	101,815	35.02
GOLDEN VALLEY	1,539	38,205	10,002	21,247	69,454	45.13
GRAND FORKS	51,599	138,752	308,891	430,542	878,185	17.02
GRANT	2,591	87,771	16,840	35,258	139,869	53.99
GRIGGS	2,411	63,736	15,673	26,862	106,271	44.07
HETTINGER	2,515	45,579	16,347	34,722	96,648	38.43
KIDDER	2,432	50,318	15,810	28,293	94,422	38.82
LAMOURE	3,930	60,561	25,542	40,717	126,820	32.27
LOGAN	2,078	48,484	13,509	23,153	85,146	40.97
MCHENRY	4,765	99,260	30,976	40,180	170,415	35.76
MCINTOSH	2,935	110,149	19,080	32,701	161,929	55.17
MCKENZIE	4,020	18,508	45,266	137,970	201,744	50.18
MCLEAN	7,058	93,766	45,879	91,165	230,811	32.70
MERCER	7,120	159,349	46,283	94,652	300,284	42.17
MORTON	17,301	162,104	112,456	191,355	465,916	26.93
MOUNTRAIL	2,731	65,460	18,022	23,586	107,068	39.21
NELSON	3,219	56,188	20,925	49,300	126,414	39.27
OLIVER	1,738	29,201	11,298	23,105	63,603	36.59
PEMBINA	6,744	109,572	56,346	95,347	261,265	38.74
PIERCE	3,688	89,152	23,972	56,478	169,601	45.99
RAMSEY	9,255	38,363	60,157	141,731	240,251	25.96
RANSOM	4,322	37,432	28,095	38,898	104,425	24.16
RENVILLE	2,307	35,974	14,994	19,449	70,418	30.53
RICHLAND	13,183	258,992	85,690	118,638	463,320	35.15
ROLETTE	9,324	48,641	88,108	195,887	332,636	35.68
SARGENT	3,386	27,634	22,007	30,469	80,111	23.66
SHERIDAN	1,568	33,195	10,192	20,844	64,231	40.96
SIOUX	2,746	19,336	30,915	137,204	187,455	68.28
SLOPE	662	19,088	4,304	9,142	32,533	49.14
STARK	16,667	45,663	108,338	230,125	384,126	23.05
STEELE	1,767	50,129	10,820	16,298	77,247	43.73
STUTSMAN	16,236	56,271	105,534	180,875	342,680	21.11
TOWNER	2,648	32,625	19,137	44,268	96,031	36.27
TRAILL	6,389	112,201	37,823	52,272	202,295	31.66
WALSH	10,103	74,317	90,324	157,300	321,940	31.87
WARD	42,252	136,275	274,641	356,244	767,160	18.16
WELLS	4,281	121,741	27,825	61,022	210,588	49.19
WILLIAMS	15,424	80,720	145,758	224,347	450,825	29.23
FORT BERTHOLD	3,938	3,938	44,346	138,198	186,483	47.35
IMPORTS	43,680	0	273,062	377,233	650,295	14.89
STATE TOTAL	508,271	4,086,229	3,415,317	5,756,877	13,258,424	26.09