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Economic Comparisons of Alternative Waste Management Systems on Tennessee Dairy Farms

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ECONOMIC COMPARISONS OF ALTERNATIVE WASTE MANAGEMENT SYSTEMS ON TENNESSEE DAIRY FARMS

*Russell D. Morgan and Luther H. Keller**

INTRODUCTION

The various systematic methods of collection, storage, and disposal of dairy farm waste have received increased scrutiny during the last two decades. Increases in milking herd size coupled with a decline in dairy farm numbers have been observed for the past several years (7, 9, 70). One result of this structural change has been that the quantity of dairy waste handled per dairy farm has grown at a significant rate, hence its rise as a management concern. In addition, the trend toward more herd confinement (increased time spent on concrete or small, unpaved lots) has been a significant factor contributing to the large increase in the quantity of waste that must be collected and removed. The rapid increase in value of the manurial fertilizer nutrients, especially nitrogen, during the 1970s (36, 49) focused renewed emphasis on dairy waste as a substitute for commercial fertilizer. Even though nutrient prices have stabilized in recent years, the nutrients in dairy waste are a potentially valuable resource and should be considered when analyzing the various manure management systems. Other, nonquantifiable benefits from dairy waste application to cropland include improved soil organic matter and tilth (12, 33). Thus, the economic value of dairy waste is likely to exceed its value measured strictly in nutrient terms.

Heightened environmental awareness in the 1970s led to increased public concern about waste management on dairy farms. Due mainly to the potential of dairy waste as a source of water pollution (point and nonpoint), dairy farms have been scrutinized with regard to the methods used in waste collection and disposal (3, 13). Although environmental concerns seem to have lessened somewhat, the possibility of stricter enforcement and/or imposition of more stringent guidelines does exist. The installation of new waste storage facilities and equipment or a significant modification of existing facilities would be necessary on many dairy farms to meet strict pollution guidelines. The realization of this contingency could result in a major expense to the individual dairy farmer and the dairy industry as a whole (10, 30, 18).

Scope of the Study

This study addresses the need for reliable and complete cost and return data for evaluating and comparing waste management systems used, or suitable for use, on Tennessee dairy farms. Without adequate data for objective

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comparison, the choice of a waste management system must rely primarily on subjective evaluations. Although a high value may possibly be placed on individual preferences, the dairy farm manager and others involved need to be aware of the relative costs of these preferences. Continued escalation in amounts and cost of capital and value of labor associated with waste handling systems provides incentive for installing and operating economically more efficient systems.

Obviously, waste management systems cannot be analyzed adequately in isolation from other phases of the dairy farm operation. While a cost and returns study necessarily analyzes the waste management system as a separate enterprise, the farm manager integrates this one management aspect into the whole farm plan for a more complete analysis (13). This whole-farm, integrated analysis is necessary because of the significant dissimilarities among dairy farms and dairy farm managers.

A general recommendation of a specific dairy waste management system as "best" for all dairy farms therefore is not feasible. However, if sufficient technical and economic data for the various waste management systems are available, the dairy farm manager, and any consultants involved, will be better able to select the system best suited to the specific dairy and its unique parameters. These parameters include available land, topography, weather, soil type, financial resources, herd size, and other farm enterprises.

Research Purposes and Objectives

The purpose of this study was to make a comparative economic evaluation of the various waste management systems most commonly found on Tennessee dairy farms. Systems determined to be most typical for Tennessee dairy farms were classified as: (1) daily haul, (2) dry stack, (3) earthen pit, (4) aboveground tank (steel or concrete), (5) single-stage lagoon, and (6) two-stage lagoon. Both three-month and six-month storage alternatives were evaluated for dry stack, earthen pit, and aboveground tank systems.

The waste management systems were compared for various sizes of milking herds and alternative confinement systems. The various sizes of milking herds considered were 80, 160, and 320 cows. The alternative confinement systems were defined as partial and total confinement.

The specific objectives of the study were

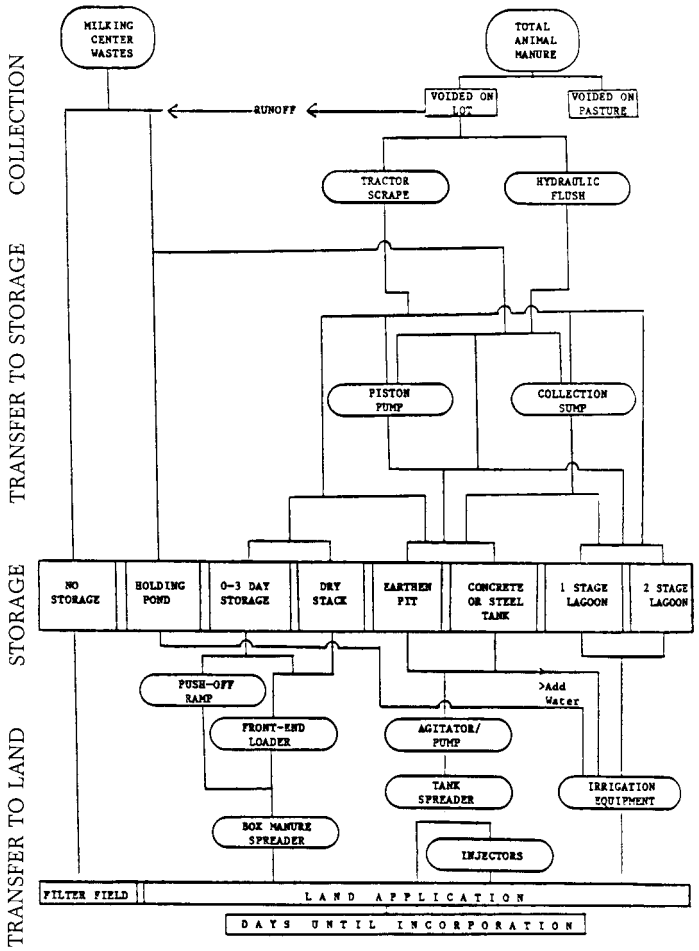
1. To describe the more common waste management systems currently in use on Tennessee dairy farms.
2. To estimate the direct costs of constructing and installing the various waste systems on synthesized dairy farms for two confinement levels, and three sizes of milking herds.
3. To estimate and compare the annualized costs and returns from the various synthesized dairy waste management systems.
4. To analyze the stability of the cost/return relationships among waste management systems to variations in certain key parameters whose values were specified by assumption.

METHODOLOGY AND PROCEDURES

Typical dairy waste management systems (those utilizing land application) can be delineated into five basic subsystems or processes: (1) collection, (2) transport to storage, (3) storage, (4) transport to land, and (5) soil incorporation. A comprehensive, though not necessarily exhaustive, schematic of potential combinations of subsystems is presented in Figure 1. Possible combinations are restricted to the more common waste systems used in conjunction with freestall housing systems.

This study was primarily concerned with the description and economic analysis of the various combinations of dairy waste handling subsystems most typically observed on Tennessee dairy farms. The analytical approach used was cost/return analysis. Economic engineering was

FIGURE 1. NETWORK OF POTENTIAL COMBINATIONS OF DAIRY WASTE MANAGEMENT SUBSYSTEMS



the technique employed in the development of the analysis.

The use of economic engineering in modeling dairy waste management systems required technical data as well as economic data. Required technical data included: (1) the amount of manure/waste to be collected, stored, and disposed; (2) labor and energy coefficients for each task in the subsystem or process; (3) nutrient loss rates during storage and after land application; and (4) mineralization rates for the manurial nutrients after soil incorporation. Reliable estimates for costs (initial, fixed, and variable) and revenues (value of manurial nutrients) were likewise essential. Economic engineering techniques were used to construct detailed budgets for the various technical and economic parameters of the selected systems.

Data on the alternative dairy waste management systems were available from various sources. The sources utilized included: (1) farm surveys and interviews, (2) experimental research results, and (3) professionals knowledgeable in the various aspects of dairy waste management systems.

Systems Selection Process

A comprehensive survey of Tennessee Grade A dairy farms by Whipple (70) was used as the primary basis for selecting the "typical" dairy waste systems. On-farm interviews were then conducted in selected Tennessee counties to obtain further information regarding cost and management practices for each of the systems. Soil Conservation Service (SCS) personnel in the selected counties were interviewed to determine the most prevalent systems in their respective areas and to obtain a list of dairy farmers utilizing these systems. Since the dairy industry in Tennessee is concentrated in East Tennessee, the counties selected were East Tennessee counties reporting large numbers of dairy farms. Furthermore, the survey results reported by Whipple (72) indicated that the waste systems utilized on East Tennessee dairy farms also predominated throughout the state.

Housing System Selection

The Whipple survey results indicated an overwhelming predominance of freestall housing over other housing systems. Therefore, only the freestall housing system was incorporated into this study.

Waste Systems Selection

Selection of seven distinct dairy waste management systems resulted from the dairy farm survey and the various interviews. The systems selected were as follows: (1) daily haul, (2) dry stack, (3) earthen pit, (4) steel aboveground tank, (5) concrete aboveground tank, (6) single-stage lagoon, and (7) two-stage lagoon.

To test for possible economies of storage size, the dry stack, earthen pit, and both aboveground tank systems were evaluated at three-month and six-month storage capacity. The three-month storage size was considered to be a minimum requirement, assuming that winter spreading of dairy waste is undesirable. Six-months storage capacity allows for the completion of a cropping season between spreadings (spring and fall). Storage is generally expected to enhance utilization of manurial nutrients, offsetting part or all of the added costs incurred due to the increased storage size (58). Since, by definition, the daily haul system has insignificant storage capacity, no variation in storage facility size was included for this system.

Additionally, since lagoon systems are commonly built with six-month storage capacity, capacity was not varied for these systems. However, two different collection methods were defined and compared for the lagoon systems. The collection methods were defined as standard (tractor and scrape) and flush (hydraulic or water flush) subsystems. These two methods were included primarily because of the Whipple farm survey results (70). The standard collection method, using a tractor and scrape, was the primary alternative to flush collection.

Herd Sizes Selected

Each identified waste system was synthesized on milking herd sizes of 80, 160, and 320 cows to test for possible economies accruing to herd size. The survey data indicated that the 80-cow herd was representative of a majority of Tennessee Grade A dairies. Likewise, the 160-cow herd size represented a significant number of Tennessee dairy farms (70). The 320-cow herd size, admittedly atypical of Tennessee dairy farms, was included primarily to determine if the relative ranking of the studied waste systems remained stable at very large herd sizes. National trends toward larger dairy herds and the assumption that smaller dairy farms would find it financially difficult to install a waste system other than daily haul led to the exclusion of smaller herd size groups.

Confinement Systems Selected

Since the degree of confinement (time spent on paved lot areas) directly affects the amount of dairy manure collected, variations in confinement methods were incorporated into the analysis. Two alternative confinement methods were defined as (1) partial confinement and (2) total confinement. Essentially, partial confinement consists of housing/feeding the milking herd on paved lots only during inclement weather (e.g., winter periods) and allowing the herd to roam/graze pasture the remaining time. Conversely, total confinement was defined to consist of housing/feeding the milking herd on paved lots 90 percent or more of the time year round, with only short periods of access to unpaved exercise or pasture areas.

Systems Modeling Process

Seventy-eight distinct dairy waste management systems resulted from incorporating three herd sizes, two confinement systems, and seven waste handling systems (with

Table 1. Dairy Herd Sizes, Confinement Systems, Waste Handling Systems and Code Designation for These Variables Used in Synthesizing the Analyzed Dairy Waste Management Systems

Variable	Code[a]
Dairy Herd Size	
80 Cows	80/
160 Cows	160/
320 Cows	320/
Confinement System	
Partial Confinement	PC/
Total Confinement	TC/
Waste Handling System	
Daily Haul	DH
Dry Stack/3-month Storage	DS/3
Dry Stack/6-month Storage	DS/6
Earthen Pit/3-month Storage	EP/3
Earthen Pit/6-month Storage	EP/6
Steel Aboveground Tank/3-month Storage	SAGT/3
Steel Aboveground Tank/6-month Storage	SAGT/6
Concrete Aboveground Tank/3-month Storage	CAGT/3
Concrete Aboveground Tank/6-month Storage	CAGT/6
Single-Stage Lagoon/Standard Collection	SSL/SC
Single-Stage Lagoon/Flush Collection	SSL/FC
Two-Stage Lagoon/Standard Collection	TSL/SC
Two-Stage Lagoon/Flush Collection	TSL/FC

[b]Codes are used in combination to identify specific dairy waste management systems. For example, the 320-cows, partial confinement, earthen pit/3-month storage system is identified as 320/PC/EP/3.

associated variations in storage capacity and collection method) into the analysis. Enumeration and code designation of system variables are found in Table 1.

Economic engineering of each specific system was accomplished through development of budgets for the various technical and economic aspects of dairy waste management systems. Basically, the purely technical budgets outlined the physical changes that occur as the dairy waste moves through the respective collection, storage, and disposal subprocesses of each waste management system. Technical budgets included: (1) Collection Budgets and (2) Storage and Application Budgets.

Budgets were also developed that included both technical and economic data. Essentially, the economic data involved valuation of the synthesized technical data. These budgets were titled as follows: (1) Annual Labor and Energy Cost Budgets and (2) Nutrient Mineralization and Annual Valuation Budgets.

"Purely economic" budgets were developed as well. Data for these budgets came from the budgets discussed above and other synthesized economic data. Economic budgets included: (1) Initial Investment Budgets; (2) Capital Recovery and Insurance/Repairs/Housing Costs Budgets; and (3) Net Annual Cost Budgets. Basically, the technical and economic budgets were developed in a "pyramid structure," each budget providing data for subsequent budgets, culminating in the Net Annual Cost Budgets. Net annual cost and initial investment were primary means for comparison of the alternative waste management systems.

Collection Budgets

The primary purpose of the collection budgets was to determine the annual quantity and nutrient content of dairy waste (including precipitation) collected with each specific waste system. Annual waste production was modeled in six two-month periods: (1) January-February, (2) March-April, (3) May-June, (4) July-August, (5) September-October, and (6) November-December. Seasonal variations in degree of herd confinement and rainfall/evapotranspiration were primarily responsible for the seasonal differences in quantity of wastes to be handed.

Parameters inherent in the development of the collection budgets are discussed below. An example collection budget is given in Appendix Table 7.

Total manure collectible. This was defined as the total amount of manure produced by the specified herd size over the specified two-month (59- to 61-day) period. Typical daily manure production and composition for various sizes of dairy cows is given in Appendix Table 1. Since Holsteins are the predominant dairy breed in the United States (2), dairy cows were assumed to be Holsteins with an average weight of 1,400 pounds.

Total manure collected. Estimates were based on the asumption that manure was produced linearly over each day (24-hour period). Thus, the total manure collected for each budget period was calculated by multiplying the total manure collectible times the respective percent of herd time spent on paved lots (%TOL). The %TOL varied seasonally according to confinement system employed (see Appendix Table 2). Nutrient composition was assumed to be similar to that of "collectible" manure.

Bedding and feed waste. Assumptions regarding the quantity of bedding and feed waste entering the waste system were based upon data from Bath et al. (2), Gilbertson et al. (17), and Moore (45). The quantity of bedding and feed wastes collected was assumed to be a function of the %TOL.

Rainfall collected. Total rainfall (precipitation) in a given budget period was multiplied by lot size[1] to determine the quantity of water potentially collected.[2] Total rainfall for each budget period was calculated as the mean of precipitation totals given by Tennessee stations reporting

[1]Lot sizes for the 80- and 160-cow herds were synthesized at a prescribed 100 sq. ft./cow. Since increased density housing is normally implemented at larger herd sizes, 75 sq. ft./cow was used for 320-cow herds (26).

[2]Only rainfall directly reaching the housing lot was included. Freestall barns, dairy parlors, and other buildings connecting the lot were assumed to be guttered and the rainfall diverted away from the housing lot, i.e., not collected into the waste system.

climatic data (16). The mean monthly rainfall is shown in Appendix Table 4. The so-called "dry" systems (daily haul and dry stack) were designed to divert as much of this lot rainfall as possible. Liquid (lagoon) and slurry (earthen pit and aboveground tank) systems were designed to collect all of the lot rainfall (runoff).

Parlor wastes. The estimated quantity and constituents of dairy parlor wastes was based on data from Bath et al. (2), Bland et al. (5), Loehr (37), Matulich et al. (40), Midwest Plan Service (41), and Zall (73). Quantities and constituents of parlor wastes assumed for each herd size are shown in Appendix Table 3.

Runoff losses. For daily haul and dry stack systems, rainfall was assumed to leave the housing lot as runoff. (Liquid and slurry systems collected all potential runoff.) The percentage of total rainfall lost as runoff was determined to be inversely proportional to %TOL.

Runoff physically removes a portion of dairy wastes from the lot surface. The literature (12, 17, 41, 43) suggests that runoff may contain up to 3.5 percent total solids by weight. Total solids (manure, bedding, and feed wastes) removed by runoff were assumed to be linearly related to %TOL. Resident in the solids removed by runoff are economically valuable nutrients. Due to different degrees of water solubility, runoff nutrients exist in different concentrations (relative to total solids content) than do manurial nutrients.

Evaporation losses. Water content of dairy wastes collected from housing/feeding lots was assumed to be reduced through evaporation. Total water lost was a function of the evapotranspiration rate, lot size, and amount of waste on the lot (a function of %TOL). Evapotranspiration rates were calculated for each budget period as the mean of evapotranspiration totals given by Tennessee stations reporting climatic data (16, 17, 61, 66) (see Appendix Table 4).

Water added. Since aboveground tank waste systems were assumed to utilize collection sumps in pumping dairy wastes into the storage facility, water had to be added to raise the collected wastes to a pumpable consistency (moisture content). The literature (57, 60) and commercial dealers suggested that dairy wastes should be at least 90 percent moisture before pumping from collection sump to storage facility.

Total wastes collected. Summation of previously discussed waste collection budget parameters resulted in "Total Wastes Collected" for each two-month period. Moisture content (percent) and nutrient content (pounds of N, P, and K) were calculated in addition to the volume and weight of dairy waste collected per period with each system. These totals were vital in the preparation of the Storage and Application Budgets.

Storage and Application Budgets

Budgets were developed to model certain physical changes that occur to dairy wastes after the collection process (i.e., during storage and after land application). Primarily, the physical changes modeled were those affecting the volume of dairy wastes handled and the fertilizer nutrient content of these wastes. Parameters inherent in the development of Storage and Application Budgets are defined and discussed below. An example of a complete Storage and Application Budget is presented in Appendix Table 8.

Total wastes collected. Values for each parameter were obtained from the Collection Budgets. For systems utilizing storage, values for this parameter were summed over budget periods up to the specified time of land application (i.e., summation totals were given only in budget periods during which land application occurred). Since daily haul systems had little inherent storage capability, land application occurred throughout each budget period.

Storage nutrient loss. Ranges in the rates of nutrient (N, P, and K) loss during storage for the various dairy waste systems were obtained from several secondary data sources (4, 24, 34, 44, 58). The ranges in nutrient loss rates for the systems included in this study are shown in Appendix Table 5. For the basis, analysis for loss rate for N, P, and K (prior to land application) were calculated at midpoint values for each specific system during each storage period.

Rainfall on storage facility. Rainfall on unroofed waste storage facilities can add significantly to the volume of wastes handled. Costs of waste disposal likewise may rise significantly. For this reason, net rainfall[3] on the storage facility was calculated for each waste management system utilizing unroofed storage.

Water added. This parameter represented the additional water required to facilitate pumping (removal) or treatment of wastes in slurry (earthen pit and above-ground tanks) (57, 60) or liquid (lagoon) systems (31, 41).

Total wastes applied. Summation of the four parameters defined above provided total dairy wastes (and associated fertilizer nutrients) applied to cropland.

Nitrogen loss (irrigation). Ten to 30 percent of total nitrogen applied via irrigation (lagoon systems) can be lost to the air through ammonia volatilization (34). A midpoint value of 20 percent was selected for use in calculating this parameter.

Volatilization loss. The quantity of N volatilized after land application and before soil incorporation of dairy wastes was assumed to be a function of soil temperature/moisture and length of time between application and incorporation (12). Soil incorporation of dairy wastes was assumed to occur no later than four days after land application. Exceptions were systems in which dairy wastes were applied to pasture, i.e., no incorporation. Soil temperature/moisture was assumed to be warm/moist in all instances except for wastes applied in the budget period

[3]Net rainfall was calculated as precipitation minus potential evapotranspiration. (See Appendix Table 4.)

(January-February), in which case it was assumed to be cool moist (see Appendix Table 6).

Runoff losses. Manurial fertilizer nutrients may be lost via field runoff after land application if the applied wastes are not incorporated into the soil. The quantities of manurial nutrients lost by field runoff is a function of numerous variables including total rainfall, rainfall intensity, field topography, and rate of waste application. Estimates were based on the assumption that significant runoff losses of nutrients occurred only in those budget periods during which wastes were applied to pasture or otherwise were not incorporated within four days after land application. Assumed rates of (field) runoff nutrient losses were based upon data from Hensler (22, 23) and Quisenberry (51).

Total nutrients in-soil. Summation of the Storage and Application Budget parameters created a parameter termed "Total Nutrients In-Soil." These values represented the quantities of manurial nutrients, placed in (on) the soil, that are potentially available for growing crops.

Nutrient Mineralization and Valuation Budgets

Dairy waste nutrients incorporated into the soil are not 100 percent available to crops during the first year after land application. Rather, waste nutrients must be mineralized into inorganic forms that are available for crop uptake. This mineralization occurs over several years (24, 28, 35, 44, 50, 67).

Budgets were developed to model the mineralization process and determine an annual value of the nutrients applied with each waste management system. Only those nutrients that become available during the first four years after land application were modeled. The value of nutrients mineralized after this period were assumed to offset leaching and other losses that may occur after soil incorporation of wastes.

Annual values of each nutrient (N, P, or K) for each waste management system was derived by: (1) determining the annual quantity of nutrient "in-soil" (from the Storage and Application Budgets), (2) multiplying this sum by the appropriate mineralization rates, (3) applying the specific elemental nutrient prices to these mineralized values[4], (4) discounting these values to determine the present value of nutrient quantities mineralized each year, and (5) summing these discounted values. Total annual value of dairy waste could then be determined for each waste system by summing the annual values of N, P, and K for the specific system.

A mathematical representation of system-specific annual returns accruing to applied dairy waste is as follows:

$$(NH_4 - N)(.28) + \sum_{i}^{t} \sum_{y}^{t} M_i \, R_{iy} \, P_{iy} \, D_y$$

where M_i equals quantities of manurial nutrient in-soil (i = N, P, K)[5]

R_y indicates the mineralization rate in year y (y = 1–4)

P_i equals price of nutrient i

D_y indicates the discount factor for year y.

An annual value for sludge removed from TSL systems was calculated. Based on literature data (21, 31, 46, 62), removal was assumed to occur at five-year intervals over the life of the system (20 years). Recoverable nutrients in sludge were assumed to accumulate at rates of 10, 40, and 25 percent of the annually collected N, P, and K, respectively. However, only 75 percent of these collected nutrients were recovered in the first sludge removal. For all other sludge removals this recovery rate increased to 90 percent.

Nutrients in sludge were valued similarly to manurial nutrients applied annually. The present value of nutrients in the year of sludge removal was calculated similarly to the annual manurial returns described. Present values of sludge nutrients calculated for each sludge removal were discounted to Year 1 and summed. These "cumulative" present values were annualized over the life of the system (20 years) to arrive at an "annual" value of sludge nutrients applied. Addition of annual sludge value to the annual value of dairy wastes irrigated each year resulted in total annual returns to the specific TSL system.

An example of Nutrient Mineralization and Valuation Budgets can be found in Appendix Table 9.

Annual Labor and Energy Costs Budgets

Labor and energy requirements and associated costs for each dairy waste management system were synthesized for each budget period. Budget period totals were summed to determine annual labor and energy costs incurred with each waste management system.

Brief descriptions of inherent "task parameters" are presented below. Not all waste systems required the same set of task parameters. Individual task parameters may be described by one or more of the following attributes: (1) labor hours and cost, (2) tractor/equipment hours and fuel/lubrication cost, (3) electricity kilowatt-hours and cost. Labor was valued at a rate of $5.00 per hour. Fuel and lubrication costs (FLC) were calculated using equation (adapted from 6, 45, and 54):

$$FLC = \frac{HP \times LF}{K} \times [\$F \times (1 + LC\%)] \times HU$$

[4]Prices for N, P, and K (nitrogen, phosphorous, and potassium) were determined from commercial fertilizer prices obtained through local fertilizer dealers. Prices used for N, P, and K were $0.28, $0.70, and $0.18, respectively.

[5]N equals total N less NH_4-N. NH^4-N was assumed to be available for crops the first year after soil incorporation. However, organic N for dry and liquid systems was mineralized with 25, 12.5, 6.25, and 3.125 percent of the applied organic N becoming available in years 1, 2, 3, and 4, respectively. The organic N mineralization rate for slurry systems was 30, 15, and 3.75 percent (66). Mineralization rates for P and K (all systems) were 75, 10, 5, and 1 percent and 80, 8, 5, and 1 percent, respectively.

where HP equals the horsepower rating of the tractor used in the task;

LF equals the load factor (65, 70, or 75 percent if HP is $< 80 > = 80 > 100 =$ respectively)

K equals a constant for engine type (13.2 for diesel)[6];

$F equals fuel price (net of tax rebate)/gallon ($1.00/gallon is assumed);

LC indicates the lubrication cost factor as a percentage (10, 8, or 6 percent if HP is $< 80 > = 80 < 100 > =$ respectively); and

HU equals the hours of use incurred due to the task performed.

Kilowatt hours used in those tasks requiring electrical energy were estimated based on technical data by Van Arsdall (68) and Frank (15). Electricity was valued at $0.05/kwh. An example Annual Labor and Energy Cost Budget is shown in Appendix Table 10.

Technical efficiency was generally greater with larger herds due to use of larger tractors and equipment. As a result, many "task coefficients" used to approximate labor and tractor/equipment requirements of the task parameters varied according to herd size.

Daily clean. Labor and tractor/equipment hours and associated costs necessary to facilitate "daily cleaning" of housing/feeding lots associated with each system were synthesized for each budget period. With the exception of systems utilizing flush collection methods (SSL/FC and TSL/FC systems), daily cleaning was assumed to be accomplished with a 37-HP tractor and box scraper. Systems utilizing flush collection methods used a recycle pump and flush tanks instead.

Agitation/transfer. Dairy waste management systems utilizing a SAGT or CAGT storage component were assumed to require a collection sump. Wastes were collected, agitated (after sufficient water was added), and transferred (pumped) to storage. Labor and energy (electricity for agitation/transfer pump) were required for this task.

Loading. Labor and tractor/equipment hours required to load collected dairy waste into a box manure spreader were synthesized for each DH and DS system. Associated labor and fuel/lubrication costs were likewise calculated. The tractor used for daily scraping also had a mounted front-end loader.

Agitation/loading. Required labor and tractor/equipment hours for agitation of stored wastes and loading these wastes out of slurry (EP, CAGT, and SAGT) systems were synthesized. Equations derived from technical literature (20, 42, 45, 49, 55, 58) were developed to estimate labor and tractor/equipment hours necessary to complete this task. Labor costs and fuel/lubrication costs were calculated in the same manner as described earlier.

Agitation. Similar to the agitation/loading parameter for slurry systems, labor and tractor/equipment requirements were synthesized for the task of agitating dairy wastes stored in SSL systems (20, 42, 49, 58). It was assumed that SSL storage facilities were agitated prior to irrigation to prevent sludge build-up and to reduce the incidence of irrigation system blockage.

Water added. In certain instances, water was added to certain slurry and liquid systems to facilitate agitation/pumping or treatment processes of the stored dairy wastes. The amount and cost of energy required to pump necessary volumes of water were estimated based on data from Van Arsdall (68) and Frank (15).

Hauling. Using Appendix Table 9 in Christensen et al. (12) as the base source, labor and tractor/equipment hours required in hauling dairy wastes from storage to the point of, and including, land application were synthesized. All of the studied system types except SSL and TSL utilized tractor and spreader (box or tank) as a land application method (hauling).

An average field distance of 1,000 feet was assumed in calculating labor and tractor/equipment hours for systems installed for 80-cow herds. For 160- and 320-cow herds, assumed average field distance was 1,500 and 2,500 feet, respectively.

Irrigation. Dairy wastes collected and stored in liquid systems (SSL and TSL) were assumed to be land-applied with irrigation equipment, including a traveling "big gun" sprinkler. Based on data from Midwest Plan Service (41), labor requirements for this task for each liquid system were limited to moving the traveling big gun after each "set."

Because land application of dairy wastes via irrigation is much less labor intensive than alternative methods, tractor/equipment hours required for this task were significantly higher than associated labor requirements. Irrigation pumps used with SSL and TSL systems were assumed to be powered by pto linkage to tractors that varied in horsepower rating according to respective herd size.

Application rates (gpm) for herd size-specific irrigation subsystems were based on data from Midwest Plan Service (41) and Horsefield et al. (26). Tractor/equipment requirements were matched to the irrigation task for each specific herd size.

Sludge removal. Periodic sludge removal was required for TSL systems (21, 31, 37, 38, 41, 46). For this study, a five-year clean-out schedule, as used by Henderson and Bauer (21), was assumed.

Sludge removal included both agitation and irrigation. Agitation consisted of agitating the first-stage lagoon only; sludge build-up in the second-stage lagoon was assumed to be minimal. Labor and tractor/equipment hours required for the agitation task were based on data by Smith (62) and were synthesized in a manner similar to the agitation tasks associated with SSL systems. Because agitation was an infrequent task (done once every five years),

[6]All tractors were assumed to have diesel engines.

tractor-powered agitation units were assumed to be rented. A rental rate of $20 per hour was estimated.[7]

The irrigation task consisted of using waste-type irrigation equipment to apply agitated anaerobic sludge to cropland. Only 75 percent of the volume of wastes in the first-stage lagoon were irrigated to preserve an active anaerobic culture (37, 38). Calculation of labor and tractor/equipment requirements were identical to that of the irrigation task parameter for SSL systems.

Costs of completing sludge removal (labor, tractor/equipment, and equipment rental costs) were discounted to Year One using 3 percent discount factors (long-term real interest rate) (6, 11, 52). Summation of discounted values in each cost category resulted in total present value of sludge removal costs. To obtain an annual evaluation, these cost values were annualized over the life (20 years) of the system. In this way, annualized costs of sludge removal could be added to the labor and energy costs incurred each year.

Initial Investment Budgets

Total initial investment required for installation of modeled dairy waste management systems on various herd sizes utilizing two different types of confinement systems was estimated. Only equipment/facilities unique to waste handling such as manure spreaders, flush tanks, agitation pumps, and storage structures were included.

Tractors used for agitation, hauling, and irrigation were not included because their proportion of annual use devoted to waste handling is likely to be relatively small. However, tractors used for daily scraping and loading tasks were included in initial investment costs because a significant proportion of annual use is likely to be devoted to waste handling.

Other items included in calculating initial investment of the various dairy waste management systems were concrete curbing around holding/feeding lots (to prevent runoff onto or off of the lot), additional concrete needed to "link" storage structures to holding/feeding lots, and fencing around below-grade storage structures (20, 41, 58, 63, 64).

Costs of the various equipment/facilities were estimated primarily from local and national dealers and manufacturers. Only "new," retail costs were estimated for the purpose of practicality. Certain construction costs, such as excavation of below-grade storage and erection of DS storage facilities, were estimated on a per-unit basis (cubic feet of storage capacity and square feet of area covered respectively). Economies of storage size were incorporated into these calculations. Local excavation and construction companies, agricultural engineers (SCS and university), as well as other similar studies (27, 40, 45, 71) were sources of this data. Initial Investment Budgets are shown in later sections.

Capital Recovery and Insurance/Repairs/ Housing Costs Budgets

Capital recovery and insurance/repairs/housing costs were estimated for equipment/facilities used with each specific dairy waste management system. Capital recovery was summed for the components of each specific waste system.

Tractors used in agitation, hauling, and irrigation of dairy wastes (items excluded form Initial Investment Budgets) were also included. Based upon a typical annual operating usage of 800 hours (6, 53), a proportionate share of annual capital recovery and insurance/repairs/housing costs for tractors (used in waste handling tasks) were budgeted to waste handling.[8] All other equipment/facilities (including irrigation equipment) were assumed to be 100 percent devoted to waste management.

Annual costs for tractors used in the agitation and irrigation tasks during sludge removal (TSL systems) were derived by first calculating the present value of these cost parameters occurring in sludge removal years. These present values were then annualized over the life of the system. For tractors and pumps used in irrigation tasks, these annualized values were added to "actual" annual capital recovery and insurance/repairs/housing costs for those items of equipment. (Irrigation of second-stage lagoon effluent is a biannual task.)

Summation of cost parameters for individual, system-specific equipment/facilities resulted in annual capital recovery and insurance/repairs/housing costs for each waste management system. These annual system cost parameters were then utilized in respective Net Annual Cost Budgets.

A brief discussion of the parameters comprising Capital Recovery and Insurance/Repairs/Housing Costs Budgets follows. A presentation of an example budget is given in Appendix Table 11.

Initial cost. Initial cost was the basis for calculating several of the necessary cost parameters for each dairy waste management system. Most costs were taken directly from associated Initial Investment Budgets. However, since tractors used for agitation, hauling, and irrigation were not included in initial investment analysis, costs of these equipment items were estimated here. A cross-section survey of local dealers provided data on retail prices of each specific type of equipment.

Insurance/repairs/housing costs. Annual costs of insurance, repairs or maintenance, and housing or storage were approximated for components of each waste management system. Insurance costs were calculated for equipment only; rates of $12/$1,000 of initial cost and $10/$1,000 of initial cost were used for self-propelled and other equip-

[7] Based on recovery of annual ownership costs over an estimated annual usage rate of 50 to 60 hours.

[8] Total annual capital recovery (insurance/repairs/housing) costs calculated times percent of average annual use devoted to waste handling (a system-specific variable, derived from labor and energy costs budgets).

ment, respectively (53).

Annual repair (maintenance) costs were calculated as a stated percentage of initial cost. Estimated annual rates were 1.5 percent for equipment and fencing components; 1 percent was the rate used for storage facilities and structural components (45, 53).

Housing costs were related to equipment only. Calculation was based upon an estimate of $0.22/square foot of housing area required for the particular item of equipment (adapted from Tennessee budgets) (53).

Capital recovery. Capital recovery charges were dependent upon the life of the asset and interest rates. Interest rates used were 14 percent for intermediate term assets (equipment) and 12 percent for longer term assets (storage facilities, etc.), respectively (1).

Estimated capital recovery cost for TSL system components included the capitalized present value of capital recovery costs calculated for sludge removal years.

Net Annual Cost Budgets

Net annual cost was estimated on the basis of technical and economic budgets described earlier. Net annual cost for each system was calculated as follows: capital recovery plus insurance/repairs/housing costs plus equipment rental cost plus energy costs plus labor costs minus annual fertilizer value of dairy waste. Net Annual Cost Budgets are presented in later sections.

Net annual cost was the primary economic parameter used in comparing modeled dairy waste management systems. All the various aspects of waste handling systems are "netted out" in this calculation, providing one number per system that can be used as a comparative tool. This figure, more than any other, determines which waste system (and variation of that system) is the most "economical."

PHYSICAL DESCRIPTION OF MODELED DAIRY WASTE SYSTEMS

The modeled waste systems are described here in physical detail with regard to such parameters as storage structure size, tractor HP ratings, and additional installation requirements (e.g., concrete). General characteristics of all systems are discussed first. Each basic type of system (e.g., daily haul, dry stack, earthen pit) is then described.

General Characteristics Of All Systems

General characteristics for all systems (by herd size) included housing/feeding lots, gutters on adjacent buildings, and assumed daily cleaning procedures.

Housing/Feeding Lot Size

Housing/feeding lots for the 80- and 160-cow herds were synthesized at a prescribed rate of 100 sq. ft./cow. Since increased housing density is feasible for very large dairy herds, housing/feeding lots were assumed to be 75 sq. ft./cow for 320-cow herds (19). Lot sizes specified for 80-, 160-, and 320-cow herds were 8,000, 16,000, and 24,000 sq. ft., respectively.

The housing/feeding lots were assumed to exist in their entirety before the respective dairy waste management system was installed. Therefore, no cash costs (with regard to waste management) were incurred due to modification of the existing lots.

Curbing Around Holding/Feeding Lots

An assumption was made that existing housing/feeding lots did not include concrete curbing around their perimeters. Therefore, to prevent runoff from entering onto or leaving from the lot, 6-inch × 8-inch concrete curbing was installed on housing/feeding lots associated with each waste management system.

Housing/feeding lots were assumed to be essentially rectangular in shape. In each instance, the length was calculated as one and one-half times the width. Estimated concrete curbing required for 80-cow, 160-cow, and 320-cow herds (all confinement systems and waste systems) was 365, 517, and 632 linear feet, respectively.

Guttered Buildings

Freestall barns, dairy parlors, and other buildings connected to housing/feeding lots were assumed to be guttered irrespective of the waste system utilized. Guttering of buildings was assumed to be independent from dairy waste management systems, and the cost of these gutters was not incorporated into the analysis.

Average Travel Distance to Fields of Application

For a specific herd size, the average travel distance to fields of application was assumed to be constant across all dairy waste management systems requiring hauling and field application of wastes. The average travel distances used in the analysis were 1,000, 1,500, and 2,500 feet for the 80-, 160-, and 320-cow herds, respectively.

Daily Cleaning

Daily cleaning procedures associated with each system were assumed to be in accordance with proper sanitation. For example, with systems utilizing the tractor and scrape collection method, the lot was scraped no less than once every two days (daily at least 90 percent of the time). Liquid systems utilizing the flush collection method were assumed to be flushed twice daily. Additionally, collected wastes were moved to a location inaccessible by the dairy herd.

Daily Haul Systems

Physically, daily haul systems were comprised of a scraping/loading tractor, a box scrape, a box-type manure spreader, a tractor for hauling/spreading wastes, and a small concrete pad for temporary (less than four days)

storage. The scraping/loading tractor and the box scrape were assumed to be the same size (HP) for all herd sizes and confinement systems. An assumption was made that a 37-HP diesel tractor (and associated front-end loader) was utilized in all modeled daily haul systems. A six-foot-wide box scrape was also assumed to be used.

For all herd sizes and confinement schemes, general management of daily haul waste systems were assumed to include daily scraping of the housing/feeding lot. In addition, wastes were loaded and hauled to be field applied on a more or less daily basis.

Dry Stack Systems

Modeled dry stack waste management systems consisted of: (1) a scraping/loading tractor; (2) a box scrape; (3) a box manure spreader; (4) a tractor used to haul/spread the collected wastes; (5) a dry stack storage structure; and (6) additional concrete needed to link the housing/feeding lot to the dry stack. Basically, the only variations in dry stack systems installed on different herd sizes and/or confinement systems were variations in size of equipment and/or storage structures.

However, certain parameters were constant over the full range of herd sizes and confinement systems. For each dry stack system modeled, the scraping/loading tractor was assumed to be 37 HP (diesel) and included a front-end loader. Likewise, the box scrape utilized in each dry stack system was assumed to be six feet wide.

Considerable variation was found to exist in the construction of dry stack storage structures on dairy farms in East Tennessee. The greatest variation occurred in the materials used to construct the walls of dry stacks. Some variation was also found in the slope of the floor and roof construction.

SCS specifications were utilized for specifying the structures for the analysis (63, 64). Dry stack facilities were assumed to include a floor of reinforced concrete (eight inches thick) sloped at a rate of 12:1, a roof constructed over the facility, and adequate space to allow operation of loading and hauling equipment. The roof would be supported by six-inch pressure-treated posts on four foot centers and set at least four feet deep.

SCS specifications allowed the use of reinforced concrete, treated tongue-and-groove lumber, or "other approved materials" for the walls of dry stack facilities (64). In some instances, masonry blocks filled with concrete and rebar were approved for use. However, there were indications that this practice was not universally accepted. Due primarily to this and longevity/durability factors, reinforced concrete was assumed to be used for the construction of dry stack walls.

It was assumed that no topographical or physical impediments existed in the location of the dry stack facility. Therefore, the dry stack could be located with a minimum of additional poured concrete (needed to "link" the storage facility with the housing/feeding lot).

Dry stack systems utilizing three-month storage capacity were designed for the most critical storage period, December through February. Total storage volume required was calculated as [(daily per animal waste production × average %TOL) + (0.5 × lbs. daily bedding/density of bedding)] × number of animal units × number days of storage.

Earthen Pit Systems

Synthesized earthen pit dairy waste management systems consisted of: (1) a scraping tractor; (2) a box scrape; (3) a tank (liquid) manure spreader; (4) a tractor used to haul/spread collected wastes; (5) a tractor for agitation/loading of stored wastes; (6) an earthen pit storage facility; (7) an agitation/removal pump; and (8) additional concrete necessary to link the housing/feeding lot with the earthen pit. A 37-HP tractor (without a front-end loader) and a six-foot box scrape were assumed for all herd sizes, confinement schemes, and storage capacities. Variations in the other parameters were modeled due to variations in herd sizes, confinement systems, and/or storage capacity.

Variations in equipment were due only to variations in herd size while alternative confinement systems and storage capacity requirements also contributed to variations in facility size.

SCS specifications were used in modeling earthen pit storage structures. In addition to handling waste production collected, earthen pit systems were designed to: (1) collect precipitation falling on the facility; (2) collect precipitation falling on the housing/feeding lot; (3) include at least one foot of freeboard; and (4) retain the capacity to absorb a "25-year, 24-hour" storm runoff.

The interior slope of the structural walls were assumed to be 2:1 in all cases. The storage structures were modeled to be square to rectangular in shape with a maximum depth of 12 feet (20, 41, 59).

One or more push-off ramp/agitation ports were specified for each earthen pit storage facility. Multiple agitation ports were required for larger storage structures due to the limited agitation distance of agitation/removal pumps (20, 59). Structural design of these agitation ports was synthesized in accordance with SCS specifications. An assumption was made that no topographical or physical impediments existed for the location of the earthen pit. Thus, the earthen pit could be located with a minimum of additional poured concrete necessary for linkage of the storage facility with the housing/feeding lot. As with dry stack systems, earthen pit systems with a three-month storage capacity were designed for the most critical collection period (December though February).

All synthesized earthen pit storage facilities included fencing as suggested by SCS (63, 64). The primary purpose of this fencing was to prevent accidental access (drowning and other hazards) by humans and animals. The size of the storage facility dictated the measurements and cost of the fencing utilized with any earthen pit sys-

tem. Generally, the number of gates associated with the fencing surrounding earthen pit storage structures corresponded to the number of agitation ports. This feature was incorporated for ease of access during the agitation/removal processes.

Aboveground Tank Systems

Modeled aboveground tank (AGT) waste management systems basically consisted of: (1) a scraping tractor, (2) a box scrape, (3) a tank (liquid) manure spreader, (4) a tractor for hauling/spreading collected wastes, (5) a tractor for agitation/loading of stored wastes, (6) an aboveground tank storage facility, (7) a collection sump (and associated agitation/transfer pump), and (8) additional concrete necessary to link the housing/feeding lot with the aboveground tank. No variation in the modeled scraping tractor or box scrape was incorporated as a result of variations in herd size, confinement system, or storage capacity. In all cases, a 37-HP tractor (no front-end loader) and six-foot box scrape were assumed.

Variations in other parameters modeled were due to variations in herd sizes, confinement systems, and/or storage capacity. Variations in equipment resulted only from differing herd sizes while alternative confinement systems and storage capacity requirements also contributed to variations in size of collection and storage facilities.

As with earthen pit systems, storage facilities associated with AGT systems were designed to: (1) collect precipitation falling on the storage facility; (2) collect precipitation from the housing/feeding lot; (3) retain the capacity to absorb a 25-year, 24-hour storm runoff; and (4) include at least six inches of freeboard in addition to collection of animal wastes. AGT systems differed from earthen pit systems in that they required a collection sump. The purpose of collection sumps was preliminary waste collection, raising the moisture content to a pumpable consistency, agitation of the wastes, and transfer of the wastes to the aboveground tank. Collection sumps were connected to AGT by an underground PVC pipe. Addition of wastes from the bottom of the AGT would minimize freezing problems and would greatly reduced surface crust disturbance. Malodor problems and nitrogen loss would be curtailed as a result.

Collection sumps were modeled to provide a minimum of three-day storage capacity (a precautionary measure to guard against mechanical failures and freezing temperatures). In addition, collection sumps were modeled to utilize a separate agitation/transfer pump driven by an electric motor. Physically, collection sumps were subterranean concrete vats with a concrete supported flat "roof" or top, which in turn supported the agitation/transfer pump.

Certain parameters were inextricably linked with the AGT storage structure. As a result, they were included in the physical description and cost of the storage structure itself. These parameters included the concrete foundation or pad supporting the structure, an agitation/removal pump (and accessories) and other accessories attached to the storage structure, e.g., ladders and platforms.

Two identifiable types of AGT structures were synthesized in all cases, one with fused glass-to-steel walls and one utilizing concrete walls. Dimensions (and capacity) were unchanged as a result of the different structural components. Only cost was affected.

As an additional note, AGT storage structures, available only in certain discrete sizes, were quite inflexible with regard to meeting capacity requirements. As a result, structures of greater capacity than needed were sometimes synthesized for a given herd size/confinement system. However, utilizing the next smallest structure would result in undersizing. This sizing difficulty is a problem encountered in real farm situations. Therefore, no assumptions were made to ameliorate the inflexibility of storage structure sizes.

Single-Stage Lagoon Systems

Basic system components for single-stage waste systems (SSL) included: (1) an agitation pump; (2) an irrigation pump; (3) mainline six-inch PVC irrigation pipe; (4) a traveling "big gun" irrigation sprinkler; (5) a tractor to run the agitation pump; (6) a tractor used to run the irrigation pump; (7) additional concrete to connect the housing/feeding lot with the SSL; (8) the SSL itself; (9) fencing around the lagoon; and (10) a standard push-off ramp. Two alternative waste collection methods—hydraulic (water flush) and the standard method of tractor and scrape collection—were analyzed.

Those systems utilizing flush collection methods included as physical parameters flush tanks and a recycle pump. Basically, liquid was recycled from the far side of the synthesized lagoon to the flush tanks and used as the hydraulic medium for waste collection. The flush tanks utilized manual gates and required manual labor to initiate the flushing process.

SCS specifications were used in designing the SSL storage facilities. The storage structures were assumed to be square to rectangular in shape. Interior walls of the structures were modeled with a slope of 2.5:1, as a precaution against wall failure (32, 64, 65). Maximum depth was limited to 16 feet. SSL storage/treatment structures were fenced to prevent accidental access by animals and humans. SSL systems were designed to be "efficient," i.e., large enough to store diluted wastes for a long enough period so that it can be at least partially decomposed by bacteria.

Twice a year dewatering (land application of collected wastes) was modeled to include agitation of the SSL facility and irrigation of the agitated wastes on cropland. If water from lot runoff, cattle waterers, and milk parlor wash water added to the lagoon was insufficient, it was assumed that water was pumped from a stream, well, or

pond. Agitation was incorporated to minimize sludge buildup. It was assumed that SSL facilities would be dewatered down to the minimum design volume. Adequate bacteria population for waste decomposition could thereby be maintained.

Two-Stage Lagoon Systems

Basic system components of two-stage lagoon (TSL) systems included: (1) an irrigation pump; (2) mainline 6-inch PVC irrigation pipe; (3) a traveling big gun sprinkler; (4) a tractor to run the irrigation pump; (5) additional concrete linking the housing/feeding lot with the TSL facility; (6) a first-stage or primary lagoon; (7) a second-stage or secondary lagoon; (8) fencing around the lagoons; (9) 10-inch PVC pipe connecting the two lagoons; and (10) a standard push-off ramp. Two alternative methods of waste collection were analyzed, hydraulic flush and standard (tractor and scrape) methods.

Those systems using flush collection included as physical parameters flush tanks and a recycle pump. Generally, liquid was pumped from the second-stage lagoon into the flush tanks and used as the hydraulic medium for waste collection. Flush tanks utilized manual gates and required manual labor to initiate the flushing process. SCS specifications were followed in the design and synthesis of TSL facilities. The storage structures were assumed to be square to rectangular in shape. Interior walls were modeled with a slope of 2.5:1 (to prevent wall failure). Maximum depth was limited to 16 feet for the first stage, 8 feet for the second-stage lagoon. In addition, storage treatment structures were fenced to prevent accidental access by humans and animals. A push-off ramp similar to that modeled for EP systems was also incorporated on TSL systems.

TSL systems were modeled to be waste treatment structures, i.e., large enough to store diluted dairy wastes for a long enough period of time so that decomposition by bacteria could occur. Basically, the first-stage lagoon was a deep anaerobic structure that overflowed into a more shallow aerobic or facultative second-stage lagoon. An effluent with less odor and fewer organic solids than a SSL resulted. This advantage is especially evident where pumping of the effluent can cause plugging (31).

With regard to system management, semi-annual irrigation of effluent from the second-stage lagoon (down to the minimum design volume) was assumed. Due to the decomposed nature of the effluent, no agitation was necessary.

It is well-documented that sludge buildup occurs in dairy lagoons (31, 37, 38, 41, 46, 66). Agitation of sludge and its removal from the first-stage lagoon on a five-year rotation was modeled. Sludge removal was accomplished by irrigation using a big gun sprinkler. Since sludge removal was not an annual task, agitation pumps required in this procedure were assumed to be rented rather than purchased. It was also assumed that tractors of the size necessary to operate rented agitation pumps were already available (owned).

ECONOMIC COMPARISONS OF MODELED DAIRY WASTE MANAGEMENT SYSTEMS

Economic comparisons of modeled dairy waste management systems were focused primarily upon initial investment and net annual costs. Because of capital limitations, cash flow considerations, or other financial factors a dairy farm manager may opt for a waste management system that requires the least initial capital outlay even though this system may not be the most economically efficient system in the long run. Net annual cost was generally considered to be the primary basis for economic comparison. Net annual cost was the difference between total annual cost of the manure structure and annualized returns as measured by the retained manurial fertilizer value for each system.

Initial Investment

Dairy waste management systems were compared, with initial investment as the criteria, on each herd size and confinement system. Realistically, it does not make sense to compare waste systems across confinement systems for a given herd size (e.g., comparing the 80/PC/EP/3 system with the 80/TC/DS/6 system). An assumption was made that the choice of confinement system was not predicated upon the dairy waste system planned for use in the total dairy system or enterprise. Therefore, comparisons of partial and total confinement systems were useful only to observe the effect of increased volume of wastes on a particular type of waste system.

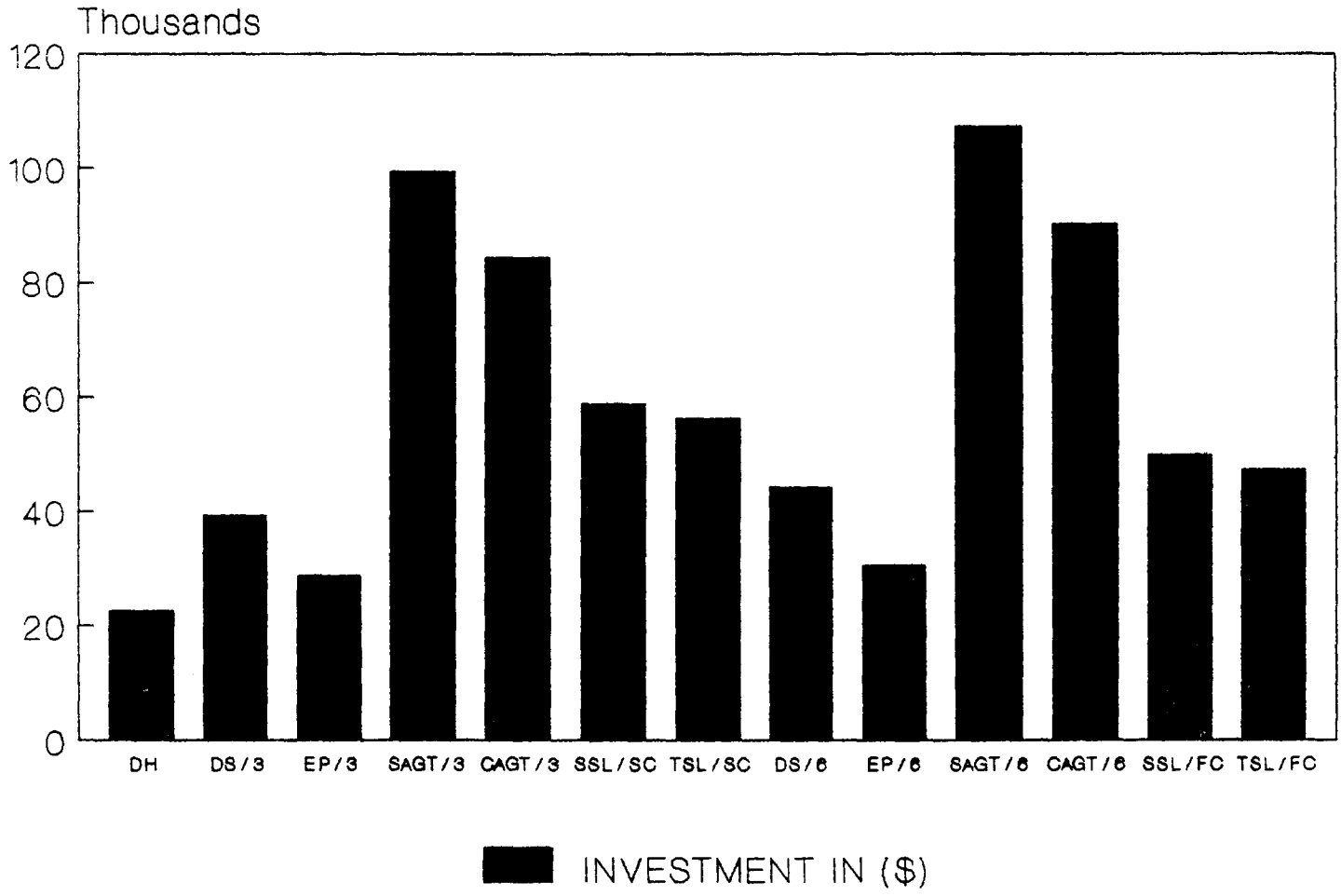
Only equipment/facilities used predominately for dairy waste management were included in this initial investment analysis. These items that would most likely need to be purchased in order to install the particular waste system. Tractors used for hauling/spreading, agitation, and irrigation were assumed to be resident on the dairy farm prior to installation of a particular dairy waste system.

Analysis of Systems on Specific Herd Sizes/Confinement Systems

Initial investment costs were viewed in terms of both total investment and investment per cow.

80/PC. Total initial investment required to install the various dairy waste management systems on 80-cow herds utilizing partial confinement ranged from $22,670 for the DH system to $107,470 for the SAGT/6 system. Viewed on a percentage basis, the SAGT/6 system required over 474 percent of the investment needed for the DH system. A tabular comparison of the initial investment

FIGURE 2. INITIAL INVESTMENTS REQUIRED TO INSTALL MODELED WASTE SYSTEMS ON THE 80/PC HERD SIZE/CONFINEMENT SYSTEM



costs of the various systems is shown in Table 2. A graphic comparison is given in Figure 2.

Storage structure cost was a major determinant of relative initial investment except for daily haul, earthen pit, and lagoon systems. Investment in storage structures for AGT systems represented more than 66 percent of the total initial outlay. However, investment in storage structures for all earthen pit systems represented an average of 14 percent of total system investment.

Lagoon system (both TSL and SSL) utilizing flush collection methods were found to require less initial outlay than similar lagoon systems using standard tractor and scrape methods. Additionally, using the methods of this study, TSL systems required less initial investment than their SSL counterparts (based on collection method).

The effect of storage size on systems modeled for the 80/PC dairy is shown in Figure 2 and Table 2. Doubling storage capacity (from three-month to six-month) of DS, EP, CAGT, and SAGT systems increased investment costs by 12, 6, 8, and 7 percent, respectively. Thus, for each storage system, investment cost increased proportionally much less than increases in capacity, particularly for the EP system.

Investment per cow was also a useful measure to compare investment requirements of various waste systems. Estimated investment for systems modeled on the 80/PC herd ranged from $283 (DH) to $1,343 (SAGT/6). Estimated investment per cow for each modeled system is shown in Table 2.

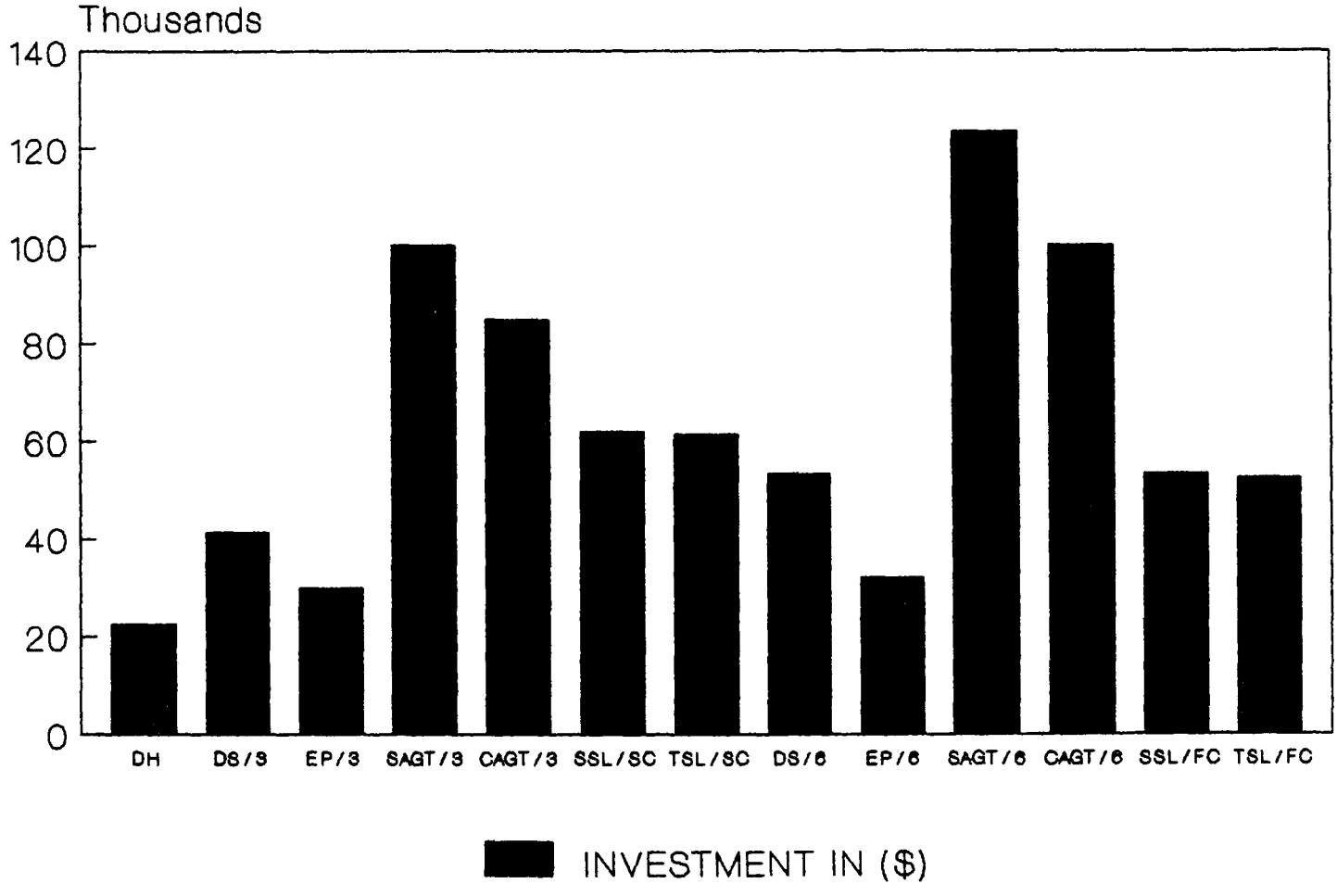
As shown in Table 2, for the 80-cow herd size utilizing partial confinement, DH required the least investment ($22,670). EP systems were 27 to 35 percent higher; DS systems were 73 to 94 percent higher. Lagoon systems, both standard collection and flush collection methods, would require two to two and one-half times as much investment as DH. The most capital intensive class of systems were the aboveground tank systems, with CAGT systems requiring the lesser investment of the two. Indeed, based upon estimates of this study, a CAGT/6 system could be installed more cheaply than SAGT/3 system. The SAGT/6 required initial investment more than three and one-half times that of the EP/6 system.

Table 2. Initial Investment Budget for Dairy Waste Management Systems Modeled for the 80/PC Herd Size/Confinement System [a]

Equipment/Structures	System/Initial Cost[b]												
	DH	DS/3	EP/3	SAGT/3	CAGT/3	SSL/SC	TSL/SC	DS/6	EP/6	SAGT/6	CAGT/6	SSL/FC	TSL/FC
Scraper tractor	16 000	16 000	12 500	12 500	12 500	12 500	12 500	16 000	12 500	12 500	12 500		
Box scrape	700	700	700	700	700	700	700	700	700	700			
Box spreader	5 000	5 000						5 000					
Tank spreader			6 300	6 300	6 300				6 300	6 300	6 300		
Agitation/removal pump			4 300			5 600			4 300			5 600	
Agitation/transfer pump				6 900	6 900					6 900	6 900		
Recycle pump												350	350
Flush tanks (manual)												3 600	3 600
Irrigation pump						7 400	7 400					7 400	7 400
Traveling big gun						12 900	12 900					12 900	12 900
Mainline PVC						7 200	7 200					7 200	7 200
Dry stack		16 020						20 790					
Earthen pit			3 330						5 010				
Aboveground tank				67 400	52 300					75 500	58 300		
Collection sump				4 560	4 560					4 560	4 560		
Single-stage lagoon						10 440						10 440	
Two-stage lagoon							13 010						13 010
Added concrete and curbing	970	1 500	1 110	1 010	1 010	1 110	1 110	1 590	1 110	1 010	1 010	1 410	1 410
Fencing, gates, etc.			490			830	1 460		590			830	1 460
Total	22 670	39 220	28 730	99 370	84 270	58 680	56 280	44 080	30 510	107 470	90 270	49 730	47 330
Per cow	383	490	359	1 242	1 053	734	704	551	381	1 343	1 128	622	592

[a]Equipment/structures used primarily for waste handling. Source: Local/national dealers and contractors.
[b]Code designations for each system are shown in Table 1.

FIGURE 3. INITIAL INVESTMENTS REQUIRED TO INSTALL MODELED WASTE SYSTEMS ON 80/TC HERD SIZE/CONFINEMENT SYSTEM



80/TC. Total initial investment required to install modeled dairy waste management systems on a 80-cow herd utilizing total confinement ranged from $22,670 for the DH system to $123,580 for the SAGT/6 system. Because the DH system utilized no storage structure, initial investment for the 80/TC herd remained the same as that for the 80/PC herd. Estimated initial capital investments required for all modeled waste systems associated with the 80/TC herd size/confinement systems are shown in Table 3. A graphic comparison of investment costs of the various systems is shown in Figure 3.

The DS/6 system modeled for this herd size/confinement system required slightly greater capital investment than either of the lagoon systems utilizing flush collection. In addition, in this model, the CAGT/6 system and the SAGT/3 system required approximately the same investment.

Storage structure remained a substantial portion of the investment cost. Storage structure cost represented over 67 percent of total investment on AGT systems (the most costly class of waste system to install). Conversely, for EP systems (the least cost waste system utilizing storage), storage structure cost represented about 18 percent of total system investment cost. Storage structure cost for lagoon systems (SSL and TSL) were 18 to 28 percent of total investment compared to 44 to 56 percent for DS systems.

Increasing storage capacity of modeled EP, DS, CAGT and SAGT waste systems from three-month to six-month storage increased investment costs by 7, 29, 18, and 24 percent respectively. Thus, investment economies of storage structure size were found to exist in all systems utilizing storage with the EP system exhibiting the greatest relative economies.

Initial investment ranged from $283 per cow for the DH system to $1,536 per cow for the SAGT/6 sytem. Investment per cow for the various modeled waste systems are shown in Table 3.

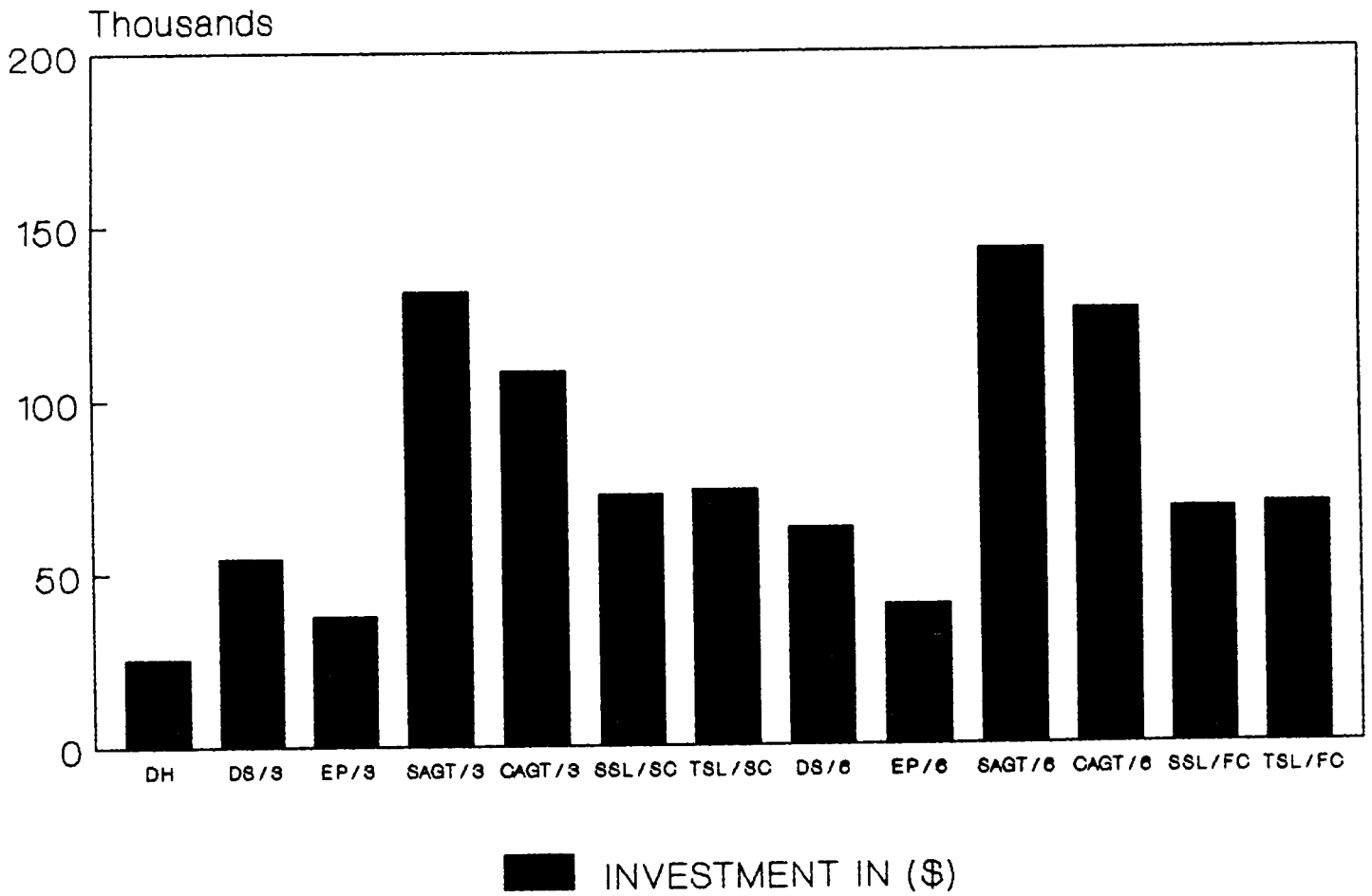
160/PC. Estimated total initial investment required to install modeled dairy waste management systems on a 160-cow herd utilizing partial confinement ranged from $25,490 for a DH system to $142,790 for a SAGT/6 system. Complete capital investment data for all dairy waste

Table 3. Initial Investment Budget for Dairy Waste Management Systems Modeled for the 80/TC Herd Size/Confinement System[a]

Equipment/Structures	System/Initial Cost[b]												
	DH	DS/3	EP/3	SAGT/3	CAGT/3	SSL/SC	TSL/SC	DS/6	EP/6	SAGT/6	CAGT/6	SSL/FC	TSL/FC
Scraper tractor	16 000	16 000	12 500	12 500	12 500	12 500	12 500	16 000	12 500	12 500	12 500		
Box scrape	700	700	700	700	700	700	700	700	700	700	700		
Box spreader	5 000	5 000						5 000					
Tank spreader			6 300	6 300	6 300				6 300	6 300	6 300		
Agitation/removal pump			4 300			5 600			4 300			5 600	
Agitation/transfer pump				6 900	6 900					6 900	6 900		
Recycle pump												350	350
Flush tanks (manual)												3 600	3 600
Irrigation pump						7 400	7 400					7 400	7 400
Traveling big gun						12 900	12 900					12 900	12 900
Mainline PVC						7 200	7 200					7 200	7 200
Dry stack		18 230						30 030					
Earthen pit			4 540						6 520				
Aboveground tank				67 400	52 300					90 900	67 600		
Collection sump				5 270	5 270					5 270	5 270		
Single-stage lagoon						13 830						13 830	
Two-stage lagoon							17 890						17 890
Added concrete and curbing	970	1 500	1 110	1 010	1 010	1 110	1 110	1 590	1 110	1 010	1 010	1 410	1 410
Fencing, gates, etc.			550			890	1 720	680				890	1 720
Total	22 670	41 430	30 000	100 080	84 890	62 130	61 420	53 420	32 110	123 580	100 280	53 180	52 470
Per cow	283	518	375	1 254	1 062	777	768	668	401	1 545	1 154	665	656

[a]Equipment/structures used primarily for waste handling. Source: Local/national dealers and contractors.
[b]Code designations for each system are shown in Table 1.

FIGURE 4. INITIAL INVESTMENTS REQUIRED TO INSTALL MODELED WASTE SYSTEMS ON THE 160/PC HERD SIZE/CONFINEMENT SYSTEM



systems modeled for the 160/PC herd size/confinement system are shown in Table 4. Relative total investment requirements for the various systems are shown graphically in Figure 4.

The DH system was by far the least capital intensive system, and the SAGT/6 system was again the most capital intensive. The SAGT/6 system required a relative investment cost 560 percent of that necessary to install the DH system.

Among systems requiring storage, EP systems had the lowest initial investment but were 45 to 55 percent above investment needed for DH. DS systems had an initial investment more than twice that of DH. For this herd size, SSL systems required less investment than their TSL counterparts. AGT systems, as a class, were the most capital intensive of the analyzed waste systems based upon initial investment. CAGT systems were less expensive than SAGT systems; based upon estimates of this study, a CAGT/6 system could be installed for less capital outlay than a SAGT/3 system. Thus, three additional months storage could be purchased at less cost by altering construction material.

Storage structure cost represented an average of almost 68 percent of total capital outlay for AGT systems compared to 19 percent for EP systems. EP systems were generally the least capital intensive systems of those incorporating storage. Doubling storage capacity (from three-month to six-month) on DS, EP, CAGT, and SAGT systems increased investment outlays by 15, 6, 16 and 9 percent, respectively. Investment economies of system storage capacity are most evident for the EP system. However, in terms of total investment, increasing storage capacity on all systems would reduce unit cost of storage significantly.

Initial investment costs ranged from $159 per cow for the DH system to $892 per cow for the SAGT/6 system. Investment per cow for each of the modeled waste systems is shown in Table 4.

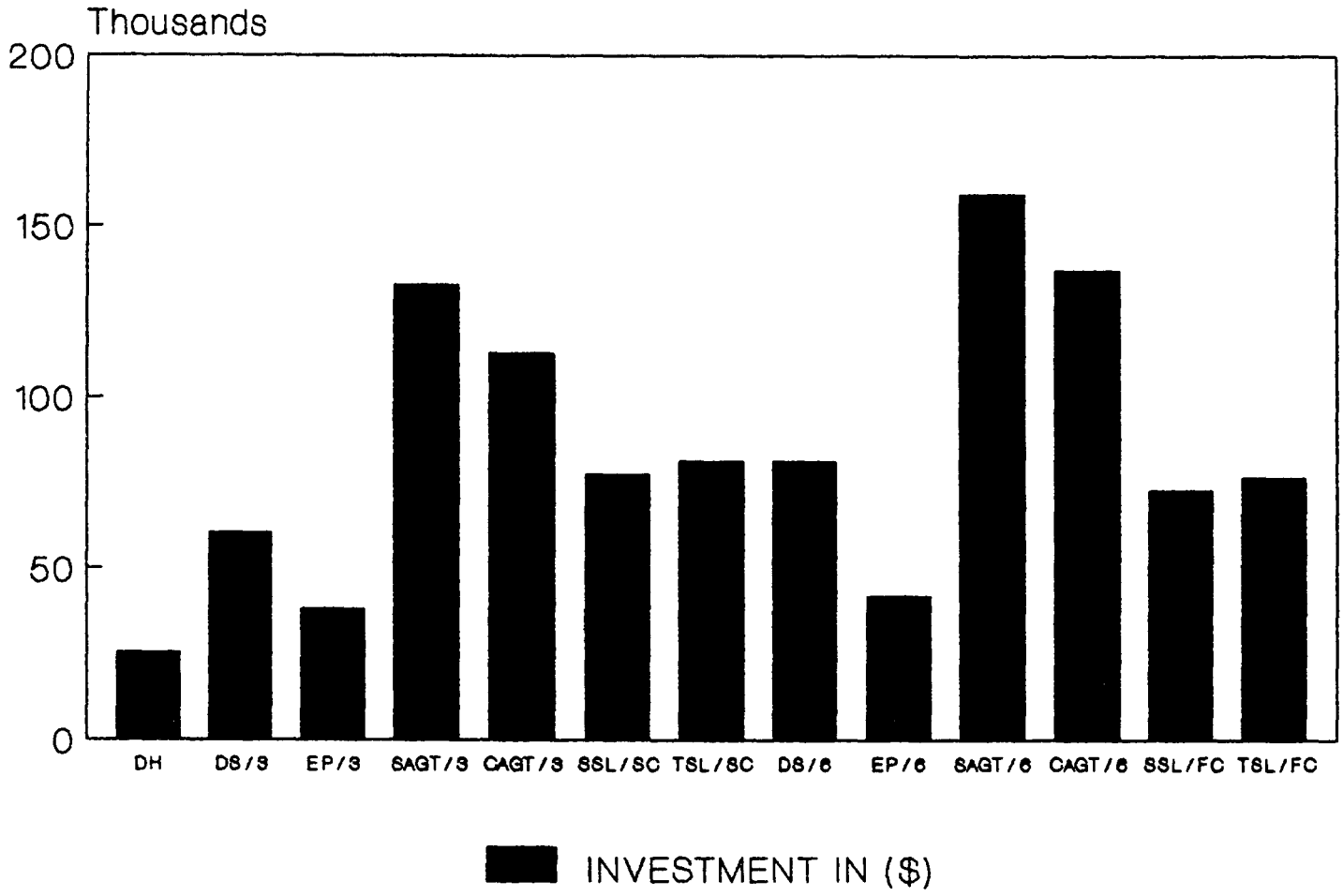
160/TC. Total capital outlays necessary to install modeled dairy waste management systems on a 160-cow herd utilizing total confinement ranged from $25,490 for a DH system to $159,300 for a SAGT/6 system. Complete

Table 4. Initial Investment Budget for Dairy Waste Management Systems Modeled for the 160/PC Herd Size/Confinement System [a]

Equipment/Structures	System/Initial Cost[b]												
	DH	DS/3	EP/3	SAGT/3	CAGT/3	SSL/SC	TSL/SC	DS/6	EP/6	SAGT/6	CAGT/6	SSL/FC	TSL/FC
Scraper tractor	16 000	16 000	12 500	12 500	12 500	12 500	12 500	16 000	12 500	12 500	12 500		
Box scrape	700	700	700	700	700	700	700	700	700	700	700		
Box spreader	7 200	7 200						7 200					
Tank spreader			11 400	11 400	11 400				11 400	11 400	11 400		
Agitation/removal pump			4 300			5 600			4 300			5 600	
Agitation/transfer pump				8 500	8 500					8 500	8 500		
Recycle pump												350	350
Flush tanks (manual)												7 200	7 200
Irrigation pump						7 400	7 400					7 400	7 400
Traveling big gun						15 100	15 100					15 100	15 100
Mainline PVC						10 800	10 800					10 800	10 800
Dry stack		28 110						36 300					
Earthen pit			6 270						8 550				
Aboveground tank				90 900	67 600					102 400	84 800		
Collection sump				5 620	5 620					5 620	5 620		
Single-stage lagoon						17 410						17 410	
Two-stage lagoon							23 010						23 010
Added concrete and curbing	1 590	2 360	1 890	1 670	1 670	1 890	1 890	2 450	1 890	1 670	1 670	2 690	2 690
Fencing, gates, etc.			640			1 040	2 220	760				1 040	2 220
Total	25 490	54 370	37 700	131 290	107 990	72 440	73 620	62 650	40 130	142 790	125 190	67 590	68 770
Per cow	159	340	236	821	675	453	460	392	251	892	782	422	430

[a]Equipment/structures used primarily for waste handling. Source: Local/national dealers and contractors.
[b]Code designations for each system are shown in Table 1.

FIGURE 5. INITIAL INVESTMENTS REQUIRED TO INSTALL MODELED WASTE SYSTEMS ON 160/TC HERD SIZE/CONFINEMENT SYSTEM



initial investment data for all dairy waste systems modeled on the 160/TC herd size/confinement system are shown in Table 5. Graphic comparisons of investments required for the various systems are shown in Figure 5.

Initial investment required to install the DH system remained the same as for the 160/PC herd size/confinement system. The most capital intensive waste system (SAGT/6) required an initial capital outlay 625 percent of that necessary to install the DH system.

EP systems required less initial investment than any of the other systems requiring storage but were 50 to 65 percent more expensive than DH. Estimated investment cost was $38,130 for EP/3 and $42,070 for EP/6. DS systems required 50 to 100 percent more investment than EP systems. AGT systems were again the most capital intensive of these systems modeled, with SAGT systems being more costly than respective CAGT systems. The relative importance of various components of investment cost is shown in Table 5.

Doubling storage capacity (from three-month to six-month) increased investment outlays by 35, 9, 22, and 20 percent for DS, EP, CAGT and SAGT systems, respectively. Substantial economies of size for each type of structure were thus evident.

Initial investment costs per cow ranged from a low of $159 for DH to $996 for the SAGT/6 system. Investment per cow for the dairy waste management systems modeled for the 160/TC herd size/confinement system are shown in Table 5.

320/PC. Total initial investment required to install modeled dairy waste management systems on a 320-cow herd utilizing partial confinement ranged from $30,060 for a DH system to $229,810 for a SAGT/6 system. Capital investment data for all dairy waste systems modeled on the 320/PC herd size/confinement system are shown in Table 6. A graphic comparison of investment cost for the various systems is shown in Figure 6.

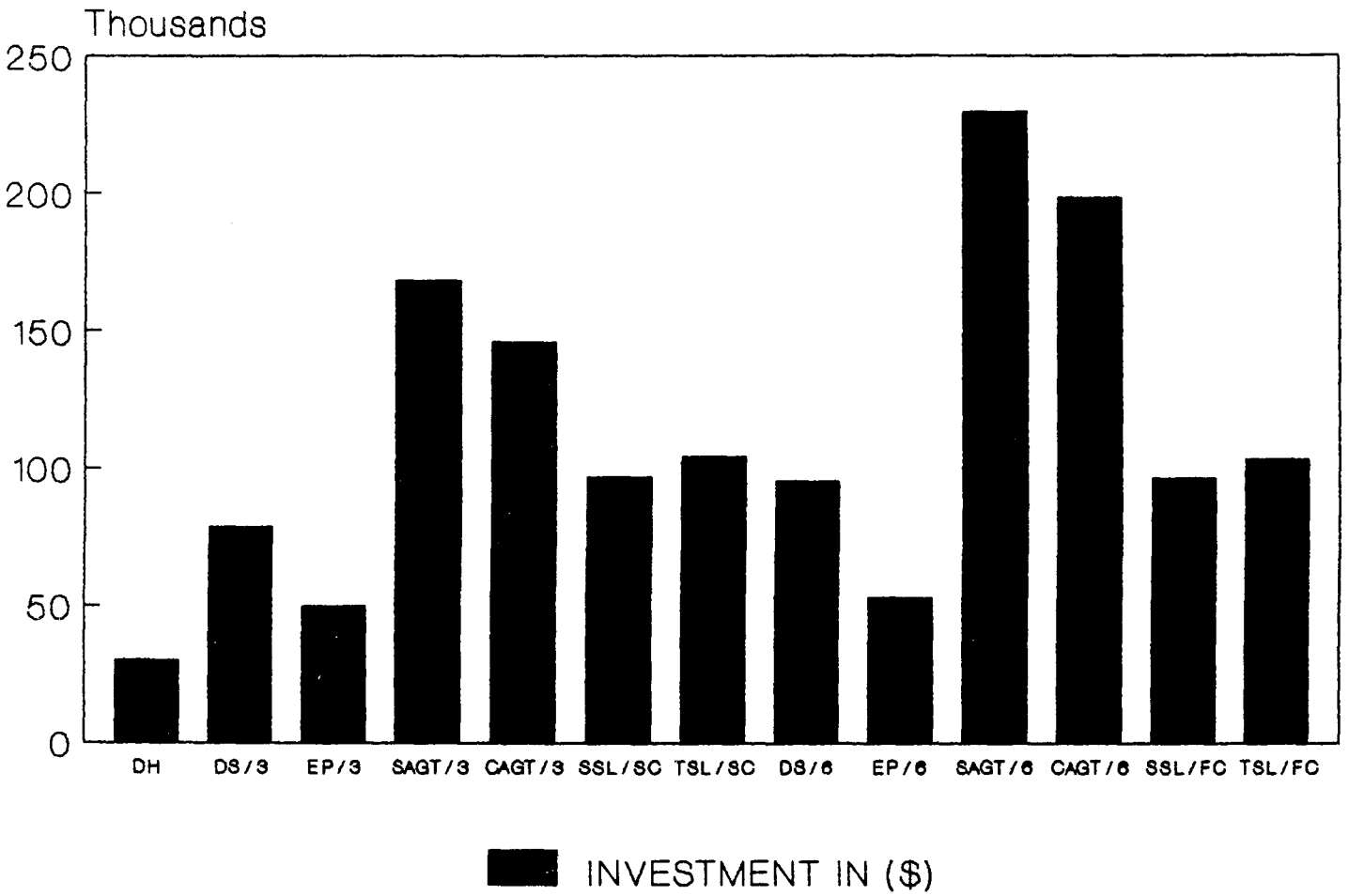
Ranked behind the DH system as the least capital intensive waste system were the EP class of waste systems, followed by the DS class. Next were SSL systems then TSL systems. Lagoon systems utilizing flush collection required less cash outlay than corresponding systems us-

Table 5. Initial Investment Budget for Dairy Waste Management Systems Modeled for the 160/TC Herd Size/Confinement System [a]

Equipment/Structures	System/Initial Cost[b]												
	DH	DS/3	EP/3	SAGT/3	CAGT/3	SSL/SC	TSL/SC	DS/6	EP/6	SAGT/6	CAGT/6	SSL/FC	TSL/FC
Scraper tractor	16 000	16 000	12 500	12 500	12 500	12 500	12 500	16 000	12 500	12 500	12 500		
Box scrape	700	700	700	700	700	700	700	700	700	700	700		
Box spreader	7 200	7 200						7 200					
Tank spreader			11 400	11 400	11 400				11 400	11 400	11 400		
Agitation/removal pump			4 300			5 600			4 300			5 600	
Agitation/transfer pump				8 500	8 500					8 500	8 500		
Recycle pump												350	350
Flush tanks (manual)												7 200	7 200
Irrigation pump						7 400	7 400					7 400	7 400
Traveling big gun						15 100	15 100					15 100	15 100
Mainline PVC						10 800	10 800					10 800	10 800
Dry stack		33 830						54 780					
Earthen pit			6 680						10 470				
Aboveground tank				91 000	70 900					117 500	95 400		
Collection sump				7 030	7 030					7 030	7 030		
Single-stage lagoon						22 450						22 450	
Two-stage lagoon							30 560						30 650
Added concrete and curbing	1 590	2 450	1 890	1 670	1 670	1 890	1 890	2 450	1 890	1 670	1 670	2 690	2 690
Fencing, gates, etc.			660			1 170	2 520	810				1 170	2 520
Total	25 490	60 180	38 130	132 000	112 700	77 610	81 470	81 330	42 070	159 300	137 200	72 760	76 620
Per cow	159	376	238	830	704	485	509	508	263	996	858	455	479

[a]Equipment/structures used primarily for waste handling. Source: Local/national dealers and contractors.
[b]Code designations for each system are shown in Table 1.

FIGURE 6. INITIAL INVESTMENTS REQUIRED TO INSTALL MODELED WASTE SYSTEMS ON THE 320/PC HERD SIZE/CONFINEMENT SYSTEM



ing the standard collection method. As with previous analyses, AGT systems ranked last using initial investment as the criterion.

An interesting comparison can be made between the EP/6 and SAGT/6 systems. Basically, both of these systems are quite similar in nature of operation; i.e., waste is stored and handled as a semisolid or near-liquid (88 to 90 percent moisture). However, in terms of cash outlay, the SAGT/6 system required more than 433 percent of the initial investment necessary to install the EP/6 system. Estimated investment costs of components of each system are shown in Table 6.

Doubling storage capacity (from three-month to six-month) on DS, EP, CAGT, and SAGT systems raised investment outlays by 21, 6, 36, and 37 percent respectively. Thus, even though economies of size exist for all types of systems, additional capacity could be obtained for the EP systems with much less cost impact than for the other type systems.

Initial investment costs per cow ranged from $94 for the DH system to $718 for the SAGT/6 system. Investment per cow for all waste systems modeled for the 320/PC herd size/confinement system is shown in Table 6.

320/TC. Total capital investment required to install modeled dairy waste management systems on a 320-cow herd utilizing total confinement ranged from $30,060 (DH system) to $258,910 (SAGT/6 system). Initial investments required for each component for all dairy waste systems modeled on the 320/TC herd size/confinement system are shown in Table 7. Graphic comparisons are shown in Figure 7.

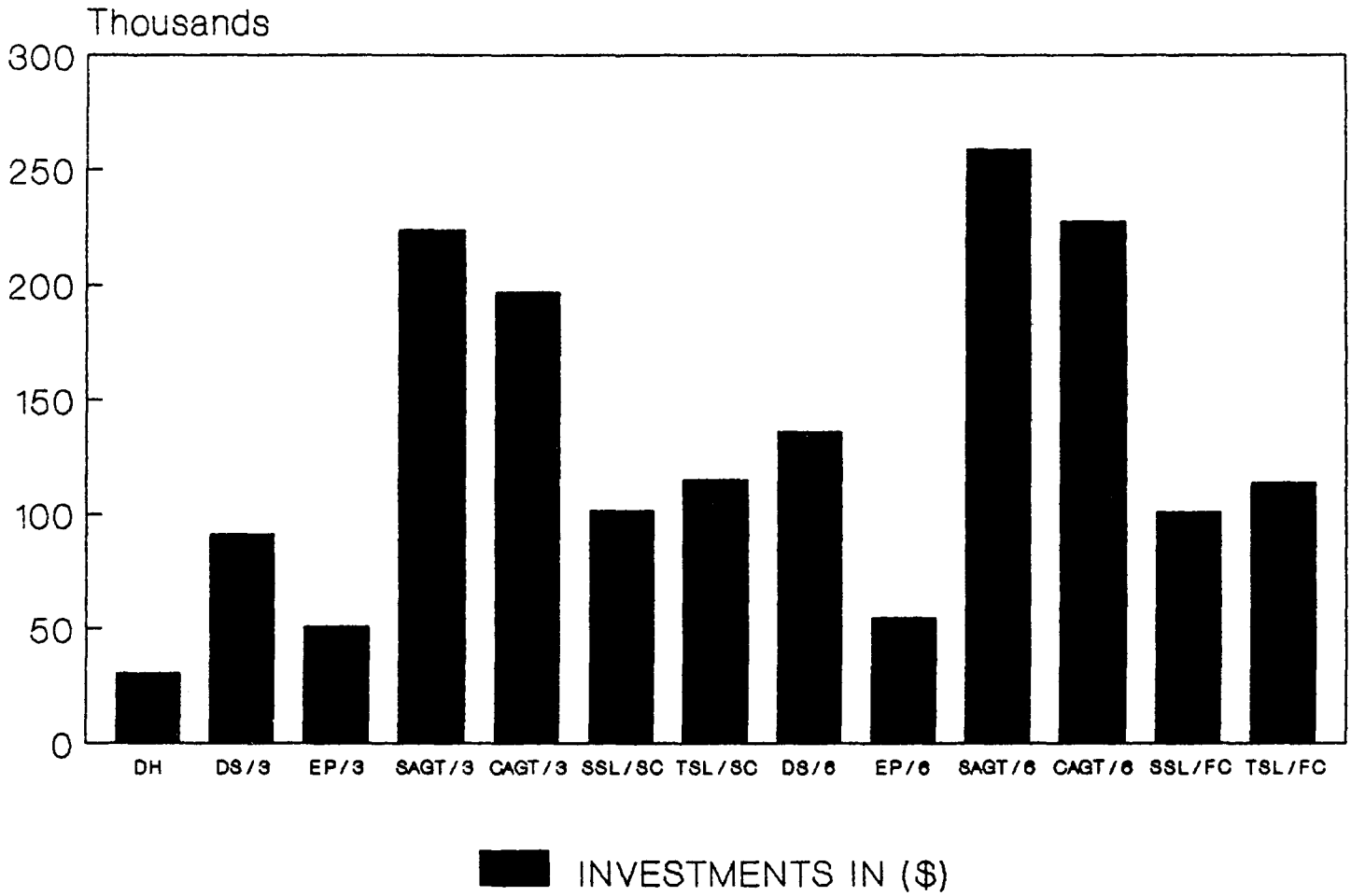
Initial investment necessary to install a DH system remained the same as it was for the 320/PC herd size/confinement system. For systems that utilized similar storage capacity, the greatest difference occurred between the SAGT/6 and EP/6 systems. The SAGT/6 system required an initial investment greater than 472 percent of that needed to install the EP/6 system. Storage structure cost was 65 percent or more of total investment for the DS and AGT systems but only 26 percent or less of total investment for the EP systems. For the lagoon systems, structure cost constituted 31 to 43 percent of total investment.

Table 6. Initial Investment Budget for Dairy Waste Management Systems Modeled for the 320/PC Herd Size/Confinement System [a]

Equipment/Structures	System/Initial Cost[2]												
	DH	DS/3	EP/3	SAGT/3	CAGT/3	SSL/SC	TSL/SC	DS/6	EP/6	SAGT/6	CAGT/6	SSL/FC	TSL/FC
Scraper tractor	16 000	16 000	12 500	12 500	12 500	12 500	12 500	16 000	12 500	12 500	12 500		
Box scrape	700	700	700	700	700	700	700	700	700	700	700		
Box spreader	11 200	11 200						11 200					
Tank spreader			18 500	18 500	18 500				18 500	18 500	18 500		
Agitation/removal pump			4 500			5 900			4 500			5 900	
Agitation/transfer pump				9 200	9 200					9 200	9 200		
Recycle pump												350	350
Flush tanks (manual)												10 800	10 800
Irrigation pump						7 400	7 400					7 400	7 400
Traveling big gun						20 700	20 700					20 700	20 700
Mainline PVC						18 000	18 000					18 000	18 000
Dry stack		46 960						63 520					
Earthen pit			9 560						12 790				
Aboveground tank				117 500	95 400					179 100	147 700		
Collection sump				7 100	7 100					7 100	7 100		
Single-stage lagoon						27 240						27 240	
Two-stage lagoon							38 960						38 960
Added concrete and curbing	2 160	3 590	3 130	2 710	2 710	3 130	3 130	3 680	3 130	2 710	2 710	4 330	4 330
Fencing, gates, etc.			810			1 390	2 870	930				1 390	2 870
Total	30 060	78 450	49 700	168 210	146 110	96 960	104 260	95 100	53 050	229 810	198 410	96 110	103 410
Per cow	94	245	155	526	457	303	326	297	166	718	620	300	323

[a]Equipment/structures used primarily for waste handling. Source: Local/national dealers and contractors.
[b]Code designations for each system are shown in Table 1.

FIGURE 7. INITIAL INVESTMENTS REQUIRED TO INSTALL MODELED WASTE SYSTEMS ON 320/TC HERD SIZE/CONFINEMENT SYSTEM



Doubling storage capacity (from three-month to six-month) on DS, EP, CAGT, and SAGT systems resulted in increased investment outlays of 50, 7, 16, and 16 percent, respectively. As for other herd sizes, expansion of capacity has proportionally less effect on total investment for the EP systems than for other systems.

Investment cost per cow ranged from $94 to $809 for the DH system and SAGT/6 system, respectively. Estimated investment per cow for each of the dairy waste systems modeled for the 320/TC herd size/confinement system is shown in Table 7.

Comparison Across Herd Sizes

Initial investment costs per cow were compared for each specific waste system as herd size was increased from 80 to 160 to 320 cows. Comparisons within a class of confinement system and across herd sizes provided some indication of economies of herd size. In all cases, substantial economies were observed in initial capital investment as herd size was increased (Table 8). For the DH system, investment cost per cow was reduced about two-thirds as herd size was increased from 80 to 320 cows. Increasing herd size from 80 to 320 cows reduced investment cost per cow for the TC/DS/6 system by 36 percent. For most of the other systems reductions were in the 45 to 55 percent range.

For systems utilizing storage, TC/SSL/SC systems exhibited the greatest investment economies accruing to herd size. As a class, the EP systems were observed to show the greatest economies of herd size. Conversely, the DS class of waste systems were found to have the least economies of herd size.

Net Annual Costs

Dairy waste management systems were also compared on each modeled herd size/confinement system with net annual cost as the criterion. Unlike the initial investment analysis, all equipment/facilities used on specific dairy waste management systems were included in net annual cost analysis. Included were equipment not predominantly used for dairy waste management, e.g., tractors used for hauling wastes. Annualized equipment/facilities costs

Table 7. Initial Investment Budget for Dairy Waste Management Systems Modeled for the 320/TC Herd Size/Confinement System [a]

Equipment/Structures	System/Initial Cost[b]												
	DH	DS/3	EP/3	SAGT/3	CAGT/3	SSL/SC	TSL/SC	DS/6	EP/6	SAGT/6	CAGT/6	SSL/FC	TSL/FC
Scraper tractor	16 000	16 000	12 500	12 500	12 500	12 500	12 500	16 000	12 500	12 500	12 500		
Box scrape	700	700	700	700	700	700	700	700	700	700	700		
Box spreader	11 200	11 200						11 200					
Tank spreader			18 500	18 500	18 500				18 500	18 500	18 500		
Agitation/removal pump			4 500			5 900			4 500			5 900	
Agitation/transfer pump				9 200	9 200					9 200	9 200		
Recycle pump												350	350
Flush tanks (manual)												10 800	10 800
Irrigation pump						7 400	7 400					7 400	7 400
Traveling big gun						20 700	20 700					20 700	20 700
Mainline PVC						18 000	18 000					18 000	18 000
Dry stack		59 390						103 680					
Earthen pit			10 600						14 490				
Aboveground tank				170 800	143 500					205 800	174 600		
Collection sump				9 500	9 500					9 500	9 500		
Single-stage lagoon						31 680						31 680	
Two-stage lagoon							45 050						49 050
Added concrete and curbing	2 160	3 680	3 130	2 710	2 710	3 130	3 130	4 460	3 130	2 710	2 710	4 330	4 330
Fencing, gates, etc.			850			1 510	3 230	990				1 510	3 230
Total	30 060	90 970	50 780	223 910	196 610	101 520	114 710	136 040	54 810	258 910	227 710	100 670	113 860
Per cow	94	284	159	700	614	317	358	425	171	809	712	315	356

[a]Equipment/structures used primarily for waste handling. Source: Local/national dealers and contractors.
[b]Code designations for each system are shown in Table 1.

Table 8. Estimated Initial Investment Cost Per Cow by Herd Size, Type of Waste System, and Degree of Confinement[a]

Herd Size/ Waste System	80	160	320	% Decrease (80→320)
PC/				
DH	283	159	94	66.9
DS/3	490	340	245	50.1
DS/6	551	392	297	46.1
EP/3	359	236	155	56.8
EP/6	381	251	166	56.5
CAGT/3	1 053	675	457	56.7
CAGT/6	1 128	782	620	45.1
SAGT/3	1 242	821	526	57.7
SAGT/6	1 343	892	718	46.5
SSL/SC	734	453	303	58.7
SSL/FC	622	422	300	51.7
TSL/SC	704	460	326	53.7
TSL/FC	592	430	323	45.4
TC/				
DH	283	159	94	66.9
DS/3	518	376	284	45.1
DS/6	668	508	425	36.3
EP/3	375	238	159	57.7
EP/6	401	263	171	57.3
CAGT/3	1 062	704	614	42.2
CAGT/6	1 254	858	712	43.2
SAGT/3	1 251	830	700	44.1
SAGT/6	1 545	996	809	47.6
SSL/SC	777	485	317	59.2
SSL/FC	665	455	315	52.6
TSL/SC	768	509	358	53.4
TSL/FC	656	479	356	45.7

[a]Code designations for each system are shown in Table 1.

were prorated based upon estimated proportionate annual use allocated to dairy waste management.

Net annual cost for each system was calculated as follows: capital recovery plus insurance/repairs/housing costs plus annual equipment rental cost plus energy costs plus labor costs minus annual fertilizer value of dairy wastes. Capital recovery, a composite method for determining cost of depreciation and interest on capital, was calculated for equipment/facilities specific to each system. Since calculation of capital recovery depended upon the life of the asset, life expectancies were estimated for all equipment/facilities. Current market interest rates were used.

Annual costs of insurance, repairs or maintenance, and housing were approximated for components of each waste system. For TSL systems, some equipment infrequently used (for sludge removal) was charged on a rental basis. Annual equipment costs incurred over time were present valued to year one; the sum of these costs were annualized over the life of the system.

Labor and energy requirements for each dairy waste management system were synthesized for each two-month budget period. Associated costs were also calculated and summed by budget period. Budget period totals were summed to determine annual labor and energy costs incurred with each waste management system. In the case of nonannual tasks, such as sludge removal from TSL systems, costs of completing these tasks in each year of occurrence were first discounted to year one and summed. Total present value of costs was then annualized over the life of the waste system and added to "real" annual labor and energy costs.

Annual fertilizer value of dairy wastes could be made only after accounting for nutrient losses during collection, storage, and application. These nutrient losses were modeled in the Collection Budgets and Storage and Application Budgets. However, nutrients incorporated into the soil are not 100 percent available to crops during the first year after land application. Rather, waste nutrients are mineralized (over several years) into inorganic forms that are available for crop uptake. Budgets were developed to model this mineralization process and determine the annual value of nutrients applied through each waste management system.

Annual values of each nutrient (N, P, and K) for each waste system was derived by: (1) determining the annual quantity of nutrients "in-soil"; (2) multiplying this sum by appropriate mineralization rates; (3) applying the specific elemental nutrient prices to the mineralized values; (4) discounting these values to determine the present value of nutrient quantities mineralized each year; and (5) summing these discounted values. Total annual value of dairy waste was determined by summing the annual values of N, P, and K for the specific system. Although it is generally recognized that manure contains inherent value as a soil enhancement (tilth and organic matter), these factors are difficult to quantify and were not included in the analysis.

Net annual cost was the primary economic parameter used in comparing modeled dairy waste management systems. All the various aspects of waste handling systems were netted out in this calculation, providing one number per system that could be used as a comparative tool.

Analysis of Systems Modeled on Specific Herd Sizes/Confinement Systems

Net annual costs for the various dairy waste management systems were compared on each specific herd size/confinement system. This comparison was made to determine which system appeared to be most economical for that herd size/confinement system.

80/PC. Estimated net annual costs for the 80/PC herd size/confinement system varied from $4,298 for the DH waste system to $15,555 for the SAGT/6 system. Component cost and benefits and net annual costs of each manure system modeled for this particular herd size/confinement system are shown in Table 9. Net annual cost of each system is shown in graphic form in Figure 8.

Among systems utilizing storage, EP systems required the least net annual costs as a class, with DS systems ranked second. The DS/3 system was less costly than the EP/6 system.

As shown in Table 9, installing greater storage capacity on specific classes of systems does not appear to be economical. On all systems for which storage capacity was varied, the systems utilizing larger storage structures incurred greater net annual cost. The slight increase in manurial fertilizer value accruing to greater storage capacity was not sufficient to offset the associated greater costs. In this study labor was charged at a constant rate throughout the year. A higher value on labor during busy seasons would enhance the benefit of waste removal scheduling and labor management. It is possible that such benefits could outweigh the "negative" net annual cost differential of a system utilizing larger storage capacity.

TSL systems were found to incur less net annual costs than SSL systems. The higher cost for the SSL systems resulted from the agitation pump requirement. Net annual costs of lagoon systems were significantly reduced when flush collection was substituted for standard collection methods. Reduced labor costs would account for most of this net annual cost differential. Labor costs were reduced by more than 68 and 74 percent on SSL and TSL systems, respectively.

The increased retention of manurial fertilizer value by AGT systems was insufficient to recoup the added costs of these systems. Net annual cost of SAGT/6 system was almost three times that of the EP/6 system. Both systems utilize quite similar technology, i.e., slurry-type waste management systems. The CAGT/6 system had net annual cost almost $2,000 less than the SAGT/3 system. Based on the analysis of this study, it would be less costly to own and operate a concrete waste storage structure with six-month capacity than a steel structure with only three-month capacity.

The systems that retained the greatest manure value were not necessarily the least-cost systems. The least-cost system (DH) retained the least manure value ($1,924). The value of manure retained was greatest for AGT systems. Manure value was 29 to 39 percent of total annual cost of the DH, DS, and EP systems but less than 22 percent of annual costs for the various AGT systems.

Labor cost tended to be a lower percent of total annual cost for those systems with the highest net annual cost. Labor cost was 12 percent or less of total annual cost for the AGT, SSL, and TSL systems but 19 percent or more of total annual cost for the EP and DS systems.

Capital recovery was the single largest cost parameter for each of the modeled waste systems and accounted for 51 to 82 percent of total annual cost among the 13 systems modeled. In dollar terms, capital recovery costs were substantially higher for the AGT systems than for any other system considered. Energy costs tended to decline relative to total annual costs as net annual costs increased. Annual energy cost, in absolute terms, was highest for the EP and AGT systems.

80/TC. Net annual costs on the 80/TC herd size/confinement system ranged from $4,768 for the EP/3 waste system to $17,119 for the SAGT/6 system. Net annual costs and component annual cost of various waste management systems modeled for the 80/TC herd size/confinement system are shown in Table 10. Net annual costs comparisons are shown graphically in Figure 9.

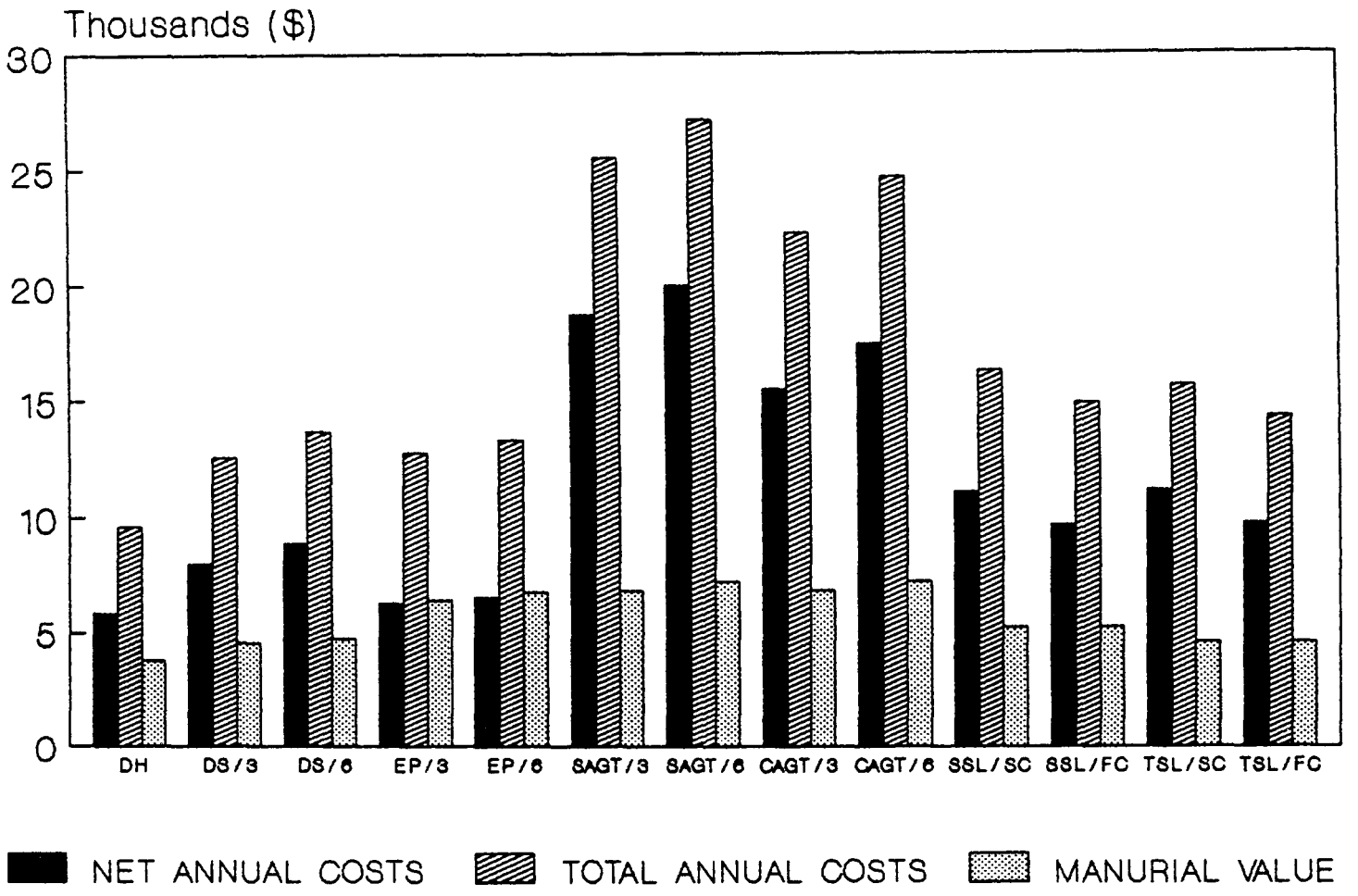
For waste management systems incorporating storage, EP systems required the least net annual costs as a class; DS systems ranked second. Indeed, both EP systems had

Table 9. Net Annual Cost Budget for 80/PC Herd Size/Confinement Systems[a]

System[b]	Capital Recovery	+Insurance/Repairs/ Housing Costs	+ Energy Costs	+ Labor Costs	= Total Annual Cost	- Manure Value	= Net Annual Cost
80/PC/							
DH	3 140	347	912	1 823	6 222	1 924	4 298
DS/3	4 804	492	767	1 575	7 638	2 323	5 315
DS/6	5 431	539	754	1 550	8 274	2 424	5 850
EP/3	4 656	567	1 237	2 038	8 398	3 242	5 256
EP/6	4 981	595	1 269	2 065	8 910	3 429	5 481
SAGT/3	13 776	1 171	1 178	1 968	18 093	3 466	14 627
SAGT/6	14 850	1 252	1 174	1 945	19 221	3 666	15 555
CAGT/3	11 775	1 020	1 178	1 968	15 941	3 466	12 475
CAGT/6	12 570	1 080	1 174	1 945	16 769	3 666	13 103
SSL/SC	9 042	1 101	864	1 303	12 310	2 639	9 671
SSL/FC	8 895	1 072	552	410	10 929	2 639	8 290
TSL/SC	8 322	936	829	1 205	11 348[c]	2 317	9 031
TSL/FC	8 175	907	517	312	9 967	2 317	7 650

[a]Data obtained from Capital Recovery/Insurance/Repairs/Housing Costs Budgets, Annual Labor and Energy Budgets, and Nutrient Mineralization and Valuation Budgets.
[b]Code designations for each system are shown in Table 1.
[c]Annualized equipment rental costs of $56 are included in the total annual cost for the TSL/SC and TSL/FC systems.

FIGURE 8. NET ANNUAL COSTS INCURRED ON DAIRY WASTE SYSTEMS MODELED FOR THE 80/PC HERD SIZE/CONFINEMENT SYSTEM



slightly lower net annual cost than the DH system. The DH system had the lowest total annual cost, but the greater value of manurial fertilizer retained offset the higher capital cost of the EP system.

In all cases, three-month storage had lower net annual cost than six-month storage for a given system type. However, as noted earlier, factors such as flexibility in labor use and choice of crop to apply dairy wastes was not modeled into the net annual cost analysis. The possibility exists that such factors could partially or wholly offset the greater net annual cost of systems incorporating enhanced storage capacity.

In terms of net annual cost for lagoon systems, flush systems were 20 percent lower than standard collection systems for both the SSL and TSL waste management systems. Savings in energy and labor costs were primarily responsible for this economic advantage.

Increased preservation of manurial fertilizer nutrients by AGT systems was insufficient to offset the substantial annual cost disadvantage of these systems. Compared to a dairy waste system incorporating quite similar technology (the EP/6 system) the SAGT/6 system incurred net annual costs almost three and one-half times as great. Additionally, it would be less costly to own and operate a concrete waste storage structure with six-month capacity than it would be for a steel structure with three-month capacity.

Manurial fertilizer value exceeded 50 percent of total annual cost of the EP systems, the two lowest net annual cost systems. Manurial value was 35 to 38 percent of total annual cost for the DS and DH systems, the third, fourth, and fifth ranking systems in terms of net annual cost. The four highest net annual cost systems (AGT) retained manurial value equal to 26 to 31 percent of total annual cost.

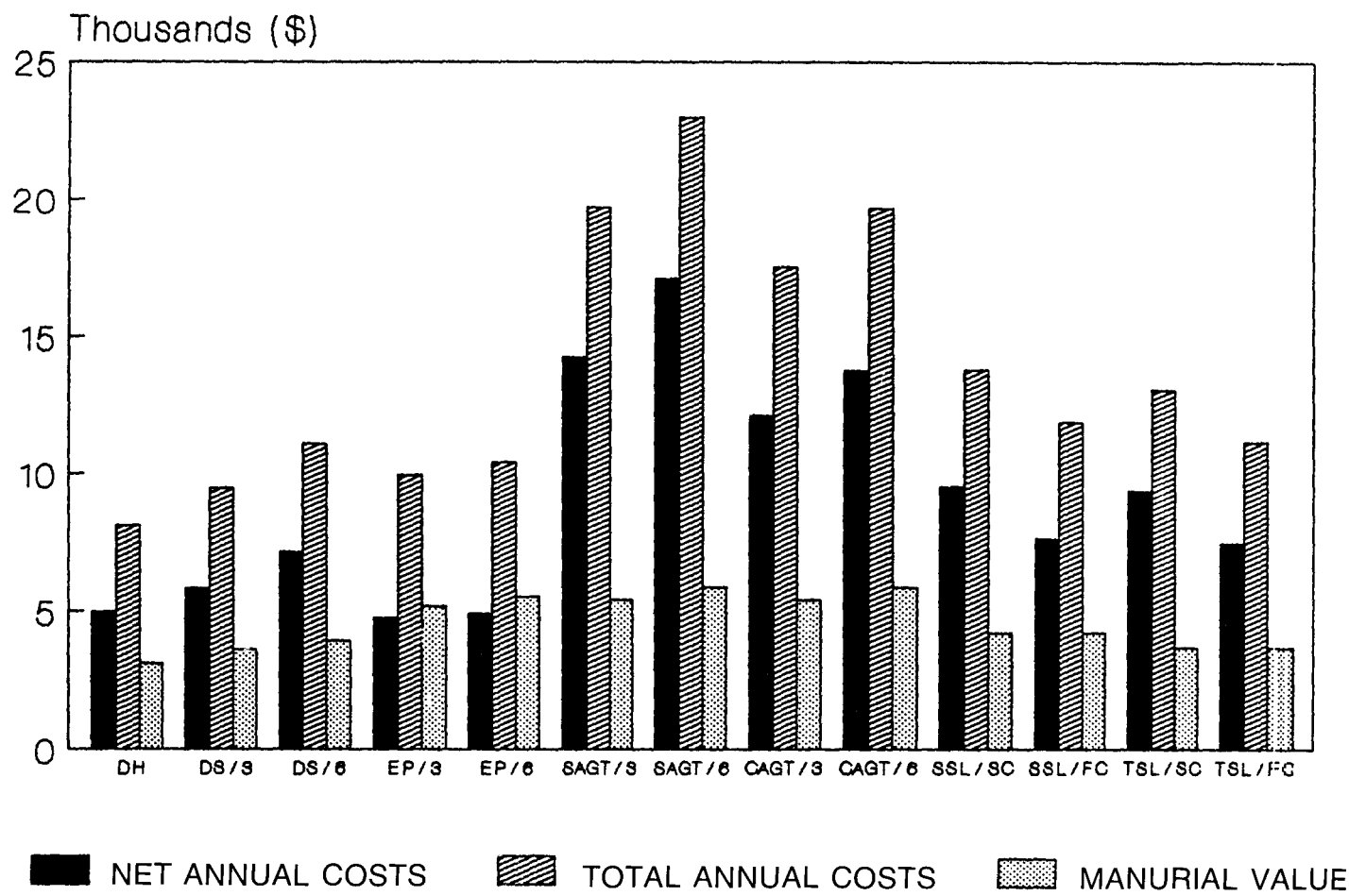
160/PC. Net annual costs for dairy waste systems modeled for the 160/PC herd size/confinement system ranged from $5,852 for DH to $19,969 for SAGT/6. For those waste systems incorporating storage, estimates indicated that EP systems required the least net annual costs as a

Table 10. Net Annual Cost Budget for 80/TC Herd Size/Confinement Systems[a]

System[b]	Capital Recovery	+ Insurance/Repairs/ Housing Costs	+ Energy Costs	+ Labor Costs	= Total Annual Cost	− Manure Value	= Net Annual Cost
80/TC/							
DH	3 185	410	1 299	2 573	8 097	3 110	4 987
DS/3	5 654	566	1 127	2 145	9 492	3 634	5 858
DS/6	7 219	681	1 105	2 098	11 103	3 934	7 169
EP/3	5 271	623	1 537	2 525	9 956	5 188	4 768
EP/6	5 643	654	1 586	2 565	10 448	5 527	4 921
SAGT/3	14 369	1 225	1 568	2 540	19 702	5 421	14 281
SAGT/6	17 483	1 459	1 555	2 498	22 995	5 876	17 119
CAGT/3	12 368	1 074	1 568	2 540	17 546	5 421	12 129
CAGT/6	14 396	1 226	1 555	2 498	19 675	5 876	13 799
SSL/SC	9 872	1 170	1 103	1 653	13 798	4 247	9 551
SSL/FC	9 530	1 123	694	548	11 895	4 247	7 648
TSL/SC	9 378	1 023	1 074	1 519	13 086[c]	3 714	9 372
TSL/FC	9 036	976	665	414	11 183	3 714	7 469

[a]Data obtained from Capital Recovery/Insurance/Repairs/Housing Costs Budgets, Annual Labor and Energy Budgets, and Nutrient Mineralization and Valuation Budgets.
[b]Code designations for each system are shown in Table 1.
[c]Annualized equipment rental costs of $92 are included in the total annual cost for the TSL/SC and TSL/FC systems.

FIGURE 9. NET ANNUAL COST INCURRED ON DAIRY WASTE SYSTEMS MODELED FOR THE 80/TC HERD SIZE/CONFINEMENT SYSTEM



class but were 8 to 12 percent higher than DH. Net annual cost for DS systems were 37 to 52 percent higher than DH. Itemized cost and estimated net annual costs of waste management systems modeled for the 160/PC herd size/confinement system are shown in Table 11. Net annual cost relationships are shown graphically in Figure 10.

On those waste systems in which storage capacity was varied, in every case the systems utilizing larger storage structures incurred greater net annual costs (Table 11). However, other factors, not incorporated into this analysis, could possibly offset this cost disadvantage. These "management factors" are farm-specific; thus only an individualized analysis could determine their relative value. With respect to lagoon systems, flush collection again showed an economic advantage over the standard collection method. Flush systems had net annual cost 65 percent greater than DH, while standard collection systems had cost 89 percent greater than DH, the least cost system.

Increased utilization of manurial fertilizer nutrients from using AGT systems was again insufficient to offset their large annual cost disadvantage. Comparing waste systems incorporating similar technology, the SAGT/6 system incurred net annual costs over three times as great as the EP/6 system. Additionally, net annual cost of CAGT systems were again considerably less than for SAGT systems.

Capital recovery accounted for 58 percent or less of total annual cost for the three least costly systems (DH, EP/3, EP/6). For the four most costly systems (AGT's) capital recovery accounted for 74 percent or more of total annual cost. Energy and labor costs were lowest for the lagoon systems but were more than offset by the higher capital recovery cost. Energy and labor efficiency may possibly be overemphasized as criteria for choosing a dairy waste management system.

160/TC. Net annual costs of dairy waste management systems modeled on the 160/TC herd size/confinement system ranged from $4,844 (EP/3) to $20,784 (SAGT/6)—a difference of $15,940, or more than three times the net annual cost of the least cost system. Estimated component and net annual costs of waste management systems modeled on the 160/TC herd size/confinement system are shown in Table 12. Graphic comparisons of net annual costs are shown in Figure 11.

Among classes of dairy waste management systems utilizing storage, EP systems incurred the least net annual costs. Indeed, EP systems incurred less net annual costs than the DH system (typically expected to be the least cost system). Net annual cost for the DH system was more than one and one-half times that incurred with the EP/3 system.

Installing greater storage capacity on those classes of waste systems for which storage capacity was varied does not appear to be justified on a net annual cost basis. For each class of system net annual costs were greater for six-month than three-month storage (Table 12).

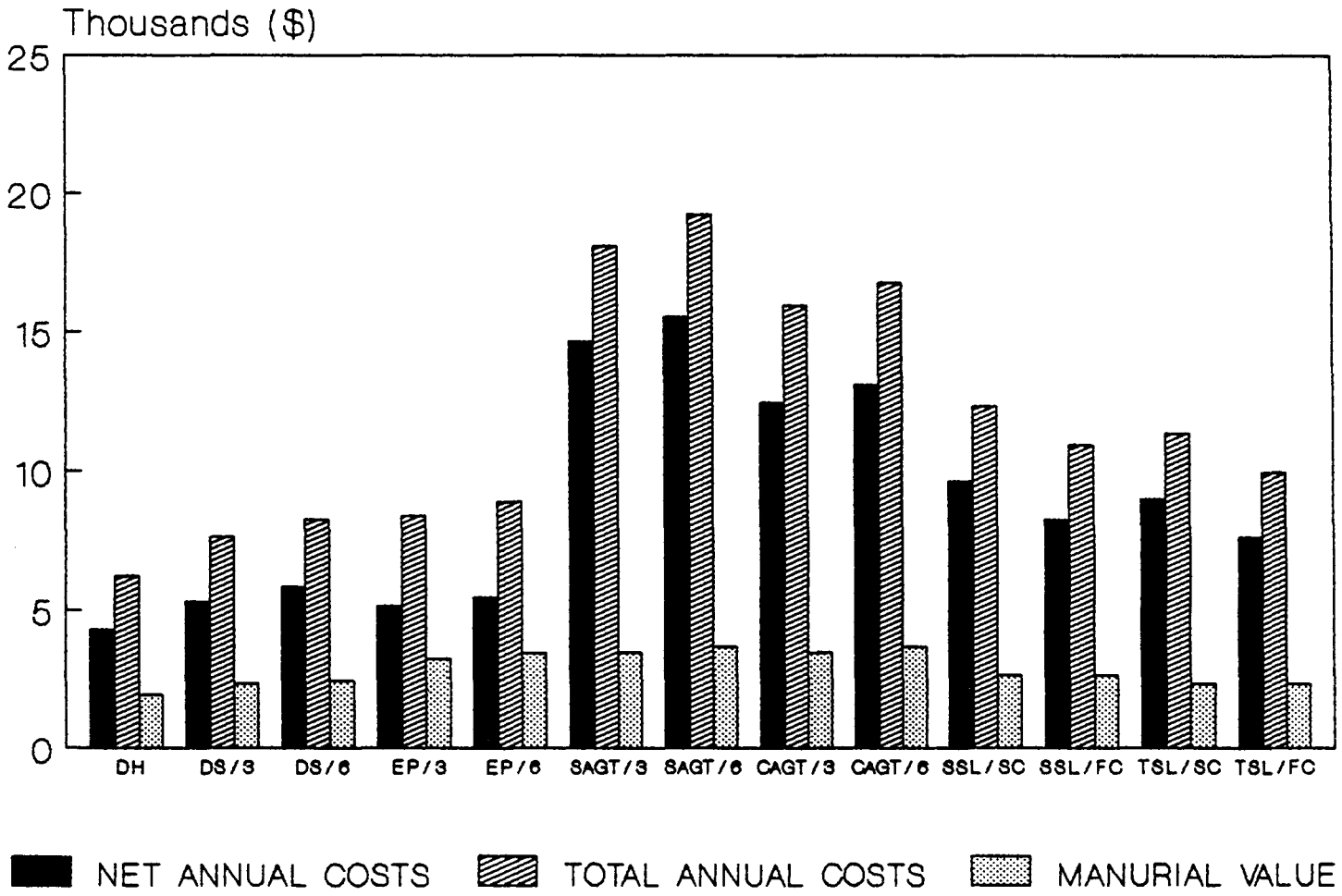
Net annual cost for SSL/FC system was lower than both DS systems. Based on estimates of this study, the SSL/FC system would be more than $1,460 less costly per annum than the DS/3 system. This finding was contrary to results of analyses, discussed earlier. Three of the lagoon systems had lower annual cost than the DS/6 system in this analysis. As in earlier analyses lagoon systems utilizing flush collection incurred fewer net annual costs than similar systems incorporating standard collection methods. Labor

Table 11. Net Annual Cost Budget for 160/PC Herd Size/Confinement Systems[a]

System[b]	Capital Recovery	+ Insurance/Repairs/ Housing Costs	+ Energy Costs	+ Labor Costs	= Total Annual Cost	- Manure Value	= Net Annual Cost
160/PC/							
DH	4 968	521	1 577	2 555	9 621	3 769	5 852
DS/3	8 064	784	1 396	2 305	12 549	4 557	7 992
DS/6	9 137	863	1 378	2 280	13 658	4 742	8 916
EP/3	7 329	848	1 914	2 658	12 749	6 415	6 334
EP/6	7 749	882	1 970	2 695	13 296	6 763	6 533
SAGT/3	19 486	1 672	1 825	2 545	25 528	6 819	18 709
SAGT/6	21 045	1 791	1 852	2 500	27 188	7 219	19 969
CAGT/3	16 399	1 493	1 825	2 545	22 262	6 819	15 443
CAGT/6	18 713	1 615	1 852	2 500	24 680	7 219	17 461
SSL/SC	11 700	1 334	1 361	1 835	16 230	5 195	11 035
SSL/FC	11 829	1 321	941	745	14 836	5 195	9 641
TSL/SC	11 333	1 194	1 305	1 697	15 617[c]	4 545	11 072
TSL/FC	11 462	1 181	885	607	14 223	4 545	9 678

[a]Data obtained from Capital Recovery/Insurance/Repairs/Housing Costs Budgets, Annual Labor and Energy Budgets, and Nutrient Mineralization and Valuation Budgets.
[b]Code designations for each system are shown in Table 1.
[c]Annualized equipment rental costs of $88 are included in the total annual cost for the TSL/SC and TSL/FC systems.

FIGURE 10. NET ANNUAL COSTS INCURRED ON DAIRY WASTE SYSTEMS MODELED FOR THE 160/PC HERD SIZE/CONFINEMENT SYSTEM



and energy cost savings appeared to be major factors contributing to the relatively lower cost of flush systems. For SSL systems, those utilizing flush collection had annual cost 23 percent less than standard collection systems. For TSL systems, flush collection systems had annual cost about 19 percent lower.

AGT systems were more effective in preserving manurial fertilizer nutrients but the value of these nutrients was insufficient to offset the considerable annual cost disadvantage of these "tank" systems. Compared to a dairy waste system incorporating quite similar technology and storage capacity (EP/6 system), the SAGT/6 system incurred net annual costs more than four times as great. The AGT systems preserved slightly more manurial value than EP systems, but annual capital recovery costs of AGT systems were substantially larger. In addition, it was less costly to own and operate a concrete waste storage structure with six-month capacity than it was for a steel structure with three-month capacity.

Capital recovery cost as a percent of total annual cost was lowest for DH, EP, and DS systems, the highest ranking systems in terms of least net annual cost. These same systems had the highest labor cost as a percent of total annual cost. Value of retained manurial fertilizer nutrients as a percent of total annual cost was lowest for AGT and TSL systems.

320/PC. Net annual costs of dairy waste systems modeled on the 320/PC herd size/confinement system ranged from $5,922 for DH to $31,772 for SAGT/6. Total annual cost of each component and net annual costs of various waste management systems modeled for the 320/PC herd size/confinement system are shown in Table 13. A graphical comparison of net annual costs of the various systems is shown in Figure 12.

Among waste systems incorporating storage, EP systems required the least net annual costs as a class. As with the 160/TC analysis, the SSL/FC was found to be less costly than the DS/3 system, a difference of $1,295.

As shown in Table 13, installation of six-month rather than three-month storage capacity (on those systems for which this parameter was varied) resulted in higher net annual cost. However, for the EP systems, the six-month

Table 12. Net Annual Cost Budget for 160/TC Herd/Size Confinement Systems[a]

System[b]	Capital Recovery	+ Insurance/Repairs/ Housing Costs	+ Energy Costs	+ Labor Costs	= Total Annual Cost	- Manure Value	= Net Annual Cost
160/TC/							
DH	6 388	1 106	2 460	3 785	13 739	6 248	7 491
DS/3	10 123	961	2 176	3 363	16 623	7 273	9 350
DS/6	12 903	1 169	2 143	3 313	19 528	7 873	11 655
EP/3	8 250	934	2 484	3 495	15 163	10 319	4 844
EP/6	8 872	982	2 564	3 553	15 971	10 954	5 017
SAGT/3	20 765	1 788	2 639	3 560	28 752	10 743	18 009
SAGT/6	24 277	2 053	2 631	3 520	32 481	11 697	20 784
CAGT/3	18 102	1 587	2 627	3 560	25 876	10 743	15 133
CAGT/6	21 348	1 832	2 619	3 520	29 319	11 697	17 622
SSL/SC	13 020	1 445	1 750	2 490	18 705	8 411	10 294
SSL/FC	12 772	1 398	1 144	980	16 294	8 411	7 883
TSL/SC	12 921	1 323	1 652	2 296	18 336[c]	5 888	12 448
TSL/FC	12 675	1 276	1 047	786	15 928	5 888	10 040

[a]Data obtained from Capital Recovery/Insurance/Repairs/Housing Costs Budgets, Annual Labor and Energy Budgets, and Nutrient Mineralization and Valuation Budgets.
[b]Code designations for each system are shown in Table 1.
[c]Annualized equipment rental costs of $144 are included in the total annual cost for the TSL/SC and TSL/FC systems.

FIGURE 11. NET ANNUAL COST INCURRED ON DAIRY WASTE SYSTEMS MODELED FOR THE 160/TC HERD SIZE/CONFINEMENT SYSTEM

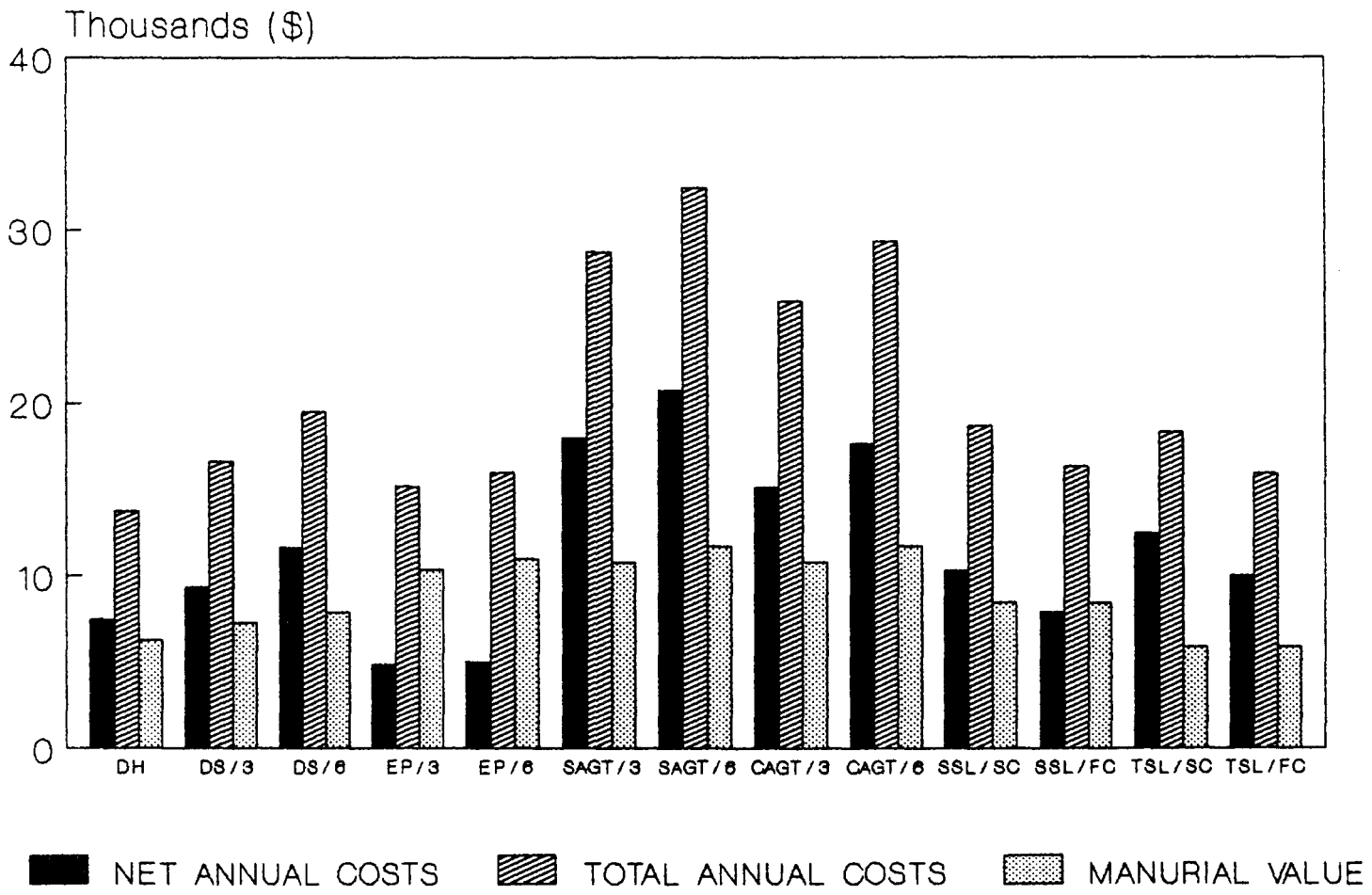
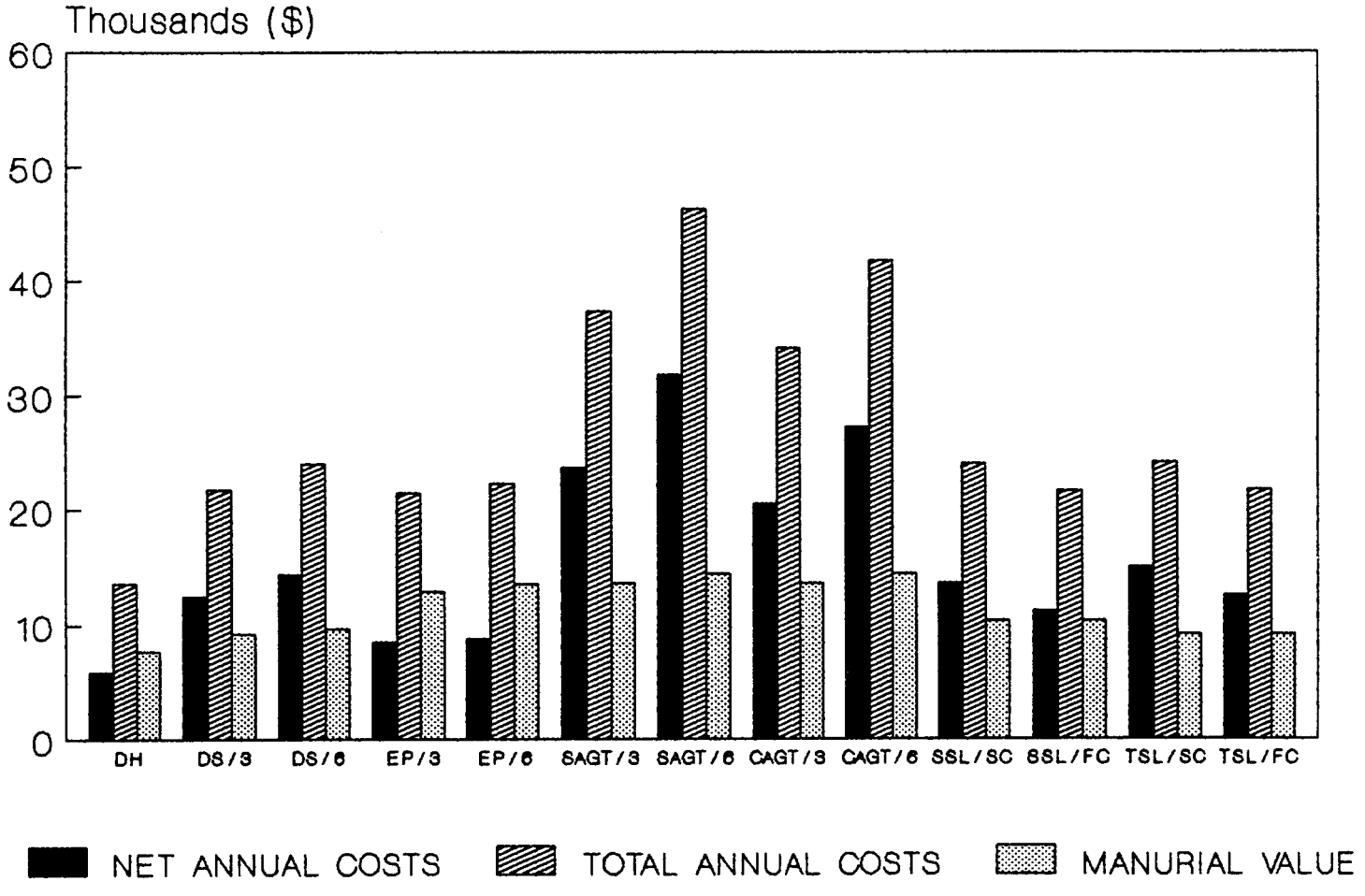


Table 13. Net Annual Cost Budget for 320/PC Herd Size/Confinement Systems[a]

System[b]	Capital Recovery	+Insurance/Repairs/ Housing Costs	+Energy Costs	+Labor Costs	=Total Annual Cost	-Manure Value	=Net Annual Cost
320/PC/							
DH	5 546	838	3 145	4 048	13 577	7 655	5 922
DS/3	13 744	1 293	2 913	3 795	21 745	9 225	12 520
DS/6	15 929	1 455	2 883	3 770	24 037	9 668	14 369
EP/3	12 022	1 326	3 882	4 185	214 156	12 895	8 520
EP/6	12 642	1 376	4 002	4 243	22 263	13 505	8 758
SAGT/3	27 180	2 376	3 708	4 048	37 312	13 619	23 693
SAGT/6	35 386	2 996	3 754	4 053	46 189	14 417	31 772
CAGT/3	24 251	2 155	3 708	4 048	34 162	13 619	20 543
CAGT/6	31 225	2 682	3 754	4 053	41 714	14 417	27 297
SSL/SC	16 899	1 810	2 483	2 858	24 050	10 378	13 672
SSL/FC	16 966	1 783	1 764	1 090	21 603	10 378	11 225
TSL/SC	17 287	1 725	2 329	2 702	24 159[c]	9 156	15 003
TSL/FC	17 354	1 698	1 610	934	21 712	9 156	12 556

[a]Data obtained from Capital Recovery/Insurance/Repairs/Housing Costs Budgets, Annual Labor and Energy Budgets, and Nutrient Mineralization and Valuation Budgets.
[b]Code designations for each system are shown in Table 1.
[c]Annualized equipment rental costs of $116 are included in the total annual cost for the TSL/SC and TSL/FC systems.

FIGURE 12. NET ANNUAL COSTS INCURRED ON DAIRY WASTE SYSTEMS MODELED FOR THE 320/PC HERD SIZE/CONFINEMENT SYSTEM



capacity system had net annual cost only $238 greater than three-month capacity. Inherent (and farm-specific) advantages of larger storage capacity were not evaluated here and could offset this cost difference.

The utilization of flush collection on lagoon systems again significantly reduced net annual costs. Both SSL and TSL systems incurred net annual cost savings of $2,447 (flush as compared to standard collection). Labor savings of almost one-third accounted for a major proportion of this economic advantage. Energy costs were also significantly lower for the lagoon systems using flush collection methods.

As for systems analyzed earlier, enhanced preservation and/or utilization of manurial fertilizer nutrients accruing to AGT systems were insufficient to offset their considerable annual cost disadvantage. Compared to the EP/6 system, the SAGT/6 system incurred net annual costs more than three and one-half times as great (or an annual disadvantage of $23,014). Both systems utilize similar waste handling technology; i.e., both are slurry systems.

Manurial fertilizer value recovered was the highest percentage of total annual cost for DH and EP systems—the three highest ranked systems in terms of least net annual cost. Manurial value recovered as a percent of total annual cost was lowest for AGT systems—the four lowest ranked systems. Lowest cost systems tended to have a higher proportion of cost in labor and energy and a smaller proportion in capital recovery. Of course, if net annual cost is the sole criterion for choice, the distribution of cost among components is unimportant. Nonetheless, particular systems are often advocated or evaluated on particular characteristics rather than the aggregate cost and benefits.

320/TC. Net annual costs of dairy waste management systems modeled on the 320/TC herd size/confinement system ranged from $6,207 (EP/6) to $34,015 (SAGT/6)—a difference of $27,808. Data on net annual costs of waste management systems modeled for the 320/TC herd size/confinement system are shown in Table 14. A graphical comparison is shown in Figure 13.

Among dairy waste management systems utilizing storage, EP systems, as a class, incurred the least net annual costs. Indeed, EP systems were found to cost less than the DH system (which is commonly expected to be the least cost system). In this analysis, the SSL/FC and TSL/FC systems incurred less net annual costs than did the DH system, contrary to the results of previous analyses.

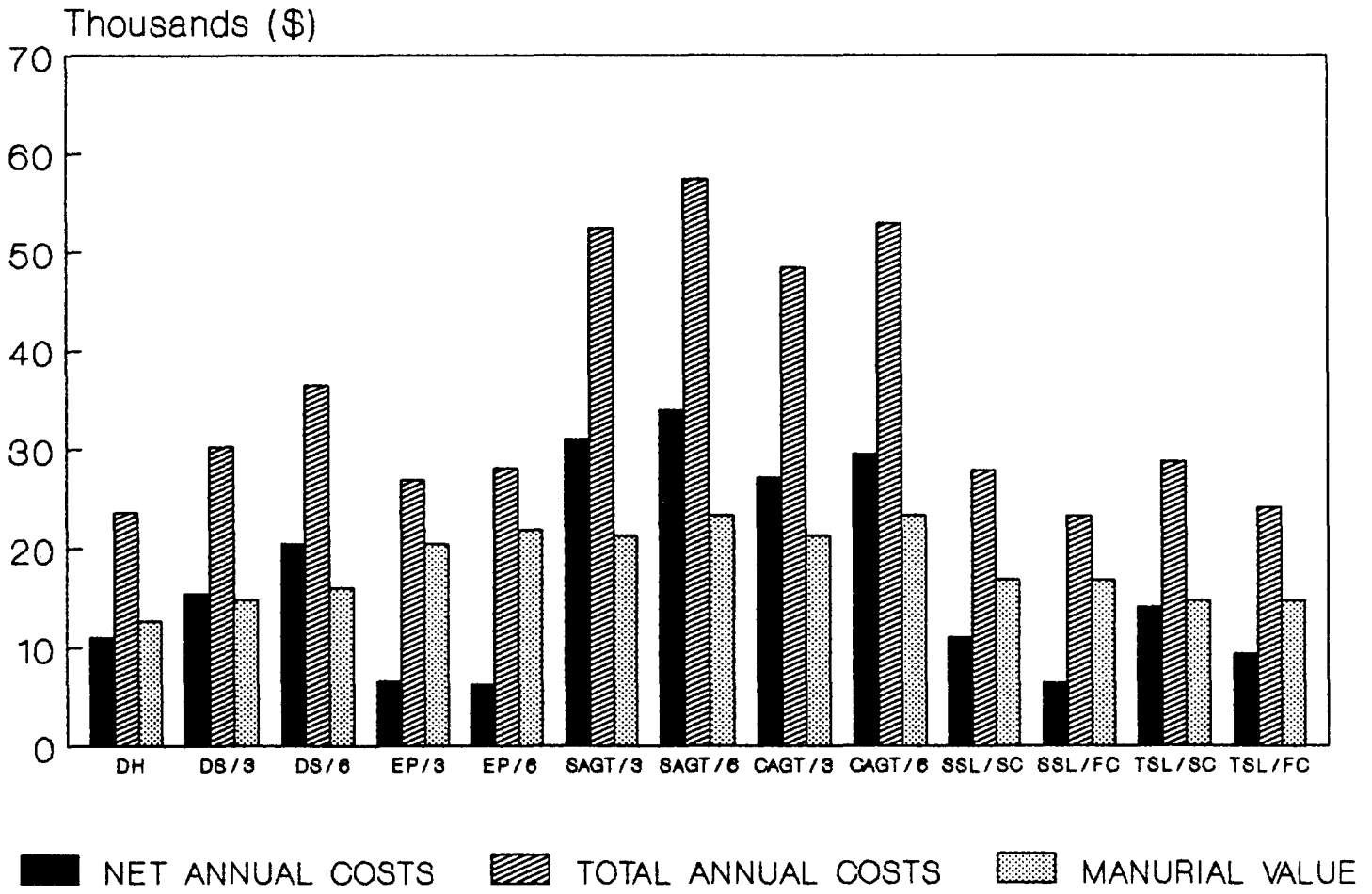
Of particular note was that the SSL/FC system ranked second in terms of lowest net annual costs. This waste system incurred $67 less net annual costs than did the EP/3 system and only $241 more than the least cost system (EP/6). Significant savings in labor and energy costs were primarily responsible for this higher ranking. As was true for other herd sizes/confinement systems, installing six-month storage capacity rather than three-month does not appear to be justified on a net annual cost basis. The only exception was EP systems where EP/6 showed about $300 less net annual cost than EP/3. In all previous analyses, six-month storage had shown a higher net annual cost than three-month capacity. Possible explanations include significant economies of storage size related to declining per unit excavation costs and the much larger volume of wastes collected with this herd size/confinement system. As supporting evidence, annual manurial fertilizer value

Table 14. Net Annual Cost Budget for 320/TC Herd Size/Confinement Systems[a]

System[b]	Capital Recovery	+ Insurance/Repairs/ Housing Costs	+ Energy Costs	+ Labor Costs	= Total Annual Cost	- Manure Value	= Net Annual Cost
320/TC/							
DH	11 226	1 106	5 057	6 270	23 659	12 699	10 960
DS/3	18 129	1 669	4 698	5 750	30 246	14 805	15 441
DS/6	24 121	2 116	4 656	5 703	36 596	16 038	20 558
EP/3	14 236	1 530	5 353	5 828	26 947	20 432	6 515
EP/6	15 029	1 594	5 551	5 928	28 102	21 895	6 207
SAGT/3	37 275	3 187	5 842	6 043	52 347	21 242	31 105
SAGT/6	41 956	3 541	5 880	6 010	57 387	23 372	34 015
CAGT/3	33 657	2 914	5 807	6 043	48 421	21 242	27 179
CAGT/6	37 821	3 229	5 845	6 010	52 905	23 372	29 533
SSL/SC	18 573	1 954	3 213	4 140	27 880	16 811	11 069
SSL/FC	17 886	1 859	2 086	1 428	23 259	16 811	6 448
TSL/SC	19 759	1 929	2 991	3 921	28 791[c]	14 728	14 063
TSL/FC	19 072	1 834	1 864	1 209	24 170	14 728	9 442

[a]Data obtained from Capital Recovery/Insurance/Repairs/Housing Costs Budgets, Annual Labor and Energy Budgets, and Nutrient Mineralization and Valuation Budgets.
[b]Code designations for each system are shown in Table 1.
[c]Annualized equipment rental costs of $191 are included in the total annual cost for the TSL/SC and TSL/FC systems.

FIGURE 13. NET ANNUAL COST INCURRED ON DAIRY WASTE SYSTEMS MODELED FOR THE 320/TC HERD SIZE/CONFINEMENT SYSTEM



for the EP/6 system was $1,463 greater than that accruing to the DS/3 system. Manurial fertilizer value for the EP/6 system was $9,196 greater than for the DH system, which had the least total annual cost (DH system). Obviously, a substantial annual cost disadvantage was offset by this nutrient value.

In comparison, the highest annual value for nutrient value retained (SAGT/6) was only $1,477 more than for the EP/6 system. However, the much higher capital costs of the SAGT/6 system more than offset its nutrient value advantage. Annual capital recovery for the SAGT/6 system was nearly $27,000 higher than for the EP/6 system.

As herd size was increased, lagoon systems compared more favorably with other systems. For the 320/TC situation all lagoon systems were less costly than either of the DS systems. Change in relative ranking probably reflect the fact that (1) per unit construction costs for dry stack facilities do not decline as significantly as per unit excavation costs for lagoon systems and (2) labor and energy cost savings for lagoon systems become more evident for larger herd sizes. Labor and energy savings are especially evident for lagoon systems utilizing flush collection. As a result, SSL/FC and TSL/FC systems were $4,621 less costly than SSL/SC and TSL/SC systems. TSL systems incurred net annual cost about $3,000 higher than comparable SSL systems.

AGT systems were again the highest cost systems analyzed. AGT systems were 4.4 to 5.5 times as expensive in terms of net annual cost as the EP/6 system, the least cost system for the 320/TC analysis. Expressed on a unit basis, the net annual cost for the AGT systems ranged from $85 to $106 per milk cow.

Manurial fertilizer value, as a percentage of total annual costs, was highest for the less costly systems. For the three highest ranked systems, manurial fertilizer value was 72 percent or more of total annual cost. For the four lowest ranked systems (AGT's), manurial value was 44 percent or less of total annual cost. As for systems analyzed earlier, capital recovery was by far the largest component of total annual cost. This parameter ranged from 79 percent of total annual cost for the TSL/FC system to 47 percent for the DH system.

Analysis of Systems Across Herd Sizes

Net annual costs per cow were compared for each specific waste system as herd size was increased from 80 to 320 cows. This analysis was an effort to observe potential economies of herd size. These comparisons were restricted within similar types of confinement systems. Since waste removal and land application is a costly process, costs per cow on a given herd size would be expected to increase if the volume of wastes collected (a function of confinement) increased.

In all instances, rather substantial net annual cost economies accruing to herd size were observed (Table 15).

PC Systems. For waste systems modeled for herds utilizing partial confinement, cost economies were most apparent on SSL and DH systems. For SSL/FC net annual costs per cow declined from $104 to $35 (about 66 percent) as herd size was increased from 80 to 320 cows. Over the same range, net annual cost for the DH systems declined from $54 to $19 (about 65 percent). DH systems were also the least cost system for all herd sizes using partial confinement. In terms of dollars, expanding from 80 to 320 cows was estimated to reduce net annual cost of dairy waste management by $69 and $35 annual savings per cow for SSL/FC and DH systems, respectively.

Table 15. Comparisons of Net Annual Cost Per Cow of Waste Management Systems by Herd Size, Type of Waste System, and Level of Confinement[a]

Herd Size/ Waste System	80	160	320	% Decrease (80→320)
PC/				
DH	54	37	19	65.6
DS/3	66	50	39	41.1
DS/6	73	56	45	38.6
EP/3	66	40	27	59.5
EP/6	69	41	27	60.1
CAGT/3	156	97	64	58.8
CAGT/6	164	109	85	47.9
SAGT/3	183	116	74	59.5
SAGT/6	194	125	99	48.9
SSL/SC	121	69	43	64.7
SSL/FC	104	60	35	66.1
TSL/SC	113	69	47	58.5
TSL/FC	96	60	39	59.0
TC/				
DH	62	47	34	45.1
DS/3	73	58	48	34.1
DS/6	90	73	64	28.3
EP/3	60	30	20	65.8
EP/6	62	31	19	68.5
CAGT/3	152	95	85	44.0
CAGT/6	172	110	92	46.5
SAGT/3	179	113	97	45.5
SAGT/6	214	130	106	50.3
SSL/SC	119	64	35	71.0
SSL/FC	96	49	20	78.9
TSL/SC	117	78	44	62.5
TSL/FC	93	63	30	68.47

[a]Code designations for each system are shown in Table 1.

Generally, if a specific waste system was less costly than a compared system at the 80-cow herd size, it would retain a relative cost advantage at the 320-cow herd size. However, this was not always true. In comparing the EP/3 and EP/6 systems, the EP/3 system incurred a cost advantage of $3 per cow at the 80-cow herd size. However, these systems were roughly equivalent when compared on 320-cow herds.

Similarly, the TSL/FC system was found to be $8 per cow less costly than the SSL/FC system on modeled 80-cow herds. On the 320-cow herd, however, the SSL/FC system had a $4 per cow cost advantage. A similar relationship existed when comparing the SSL/SC and TSL/SC systems. A possible reason for this relationship relates to spreading of the cost of an agitation pump, and its associated costs, over larger volumes of wastes. At some point, it became more economical to agitate wastes every year (using an owned pump) rather than agitate once every five years (using a rental pump). Inherent efficiencies and greater retention of manurial nutrients by SSL systems also contributed to this relationship.

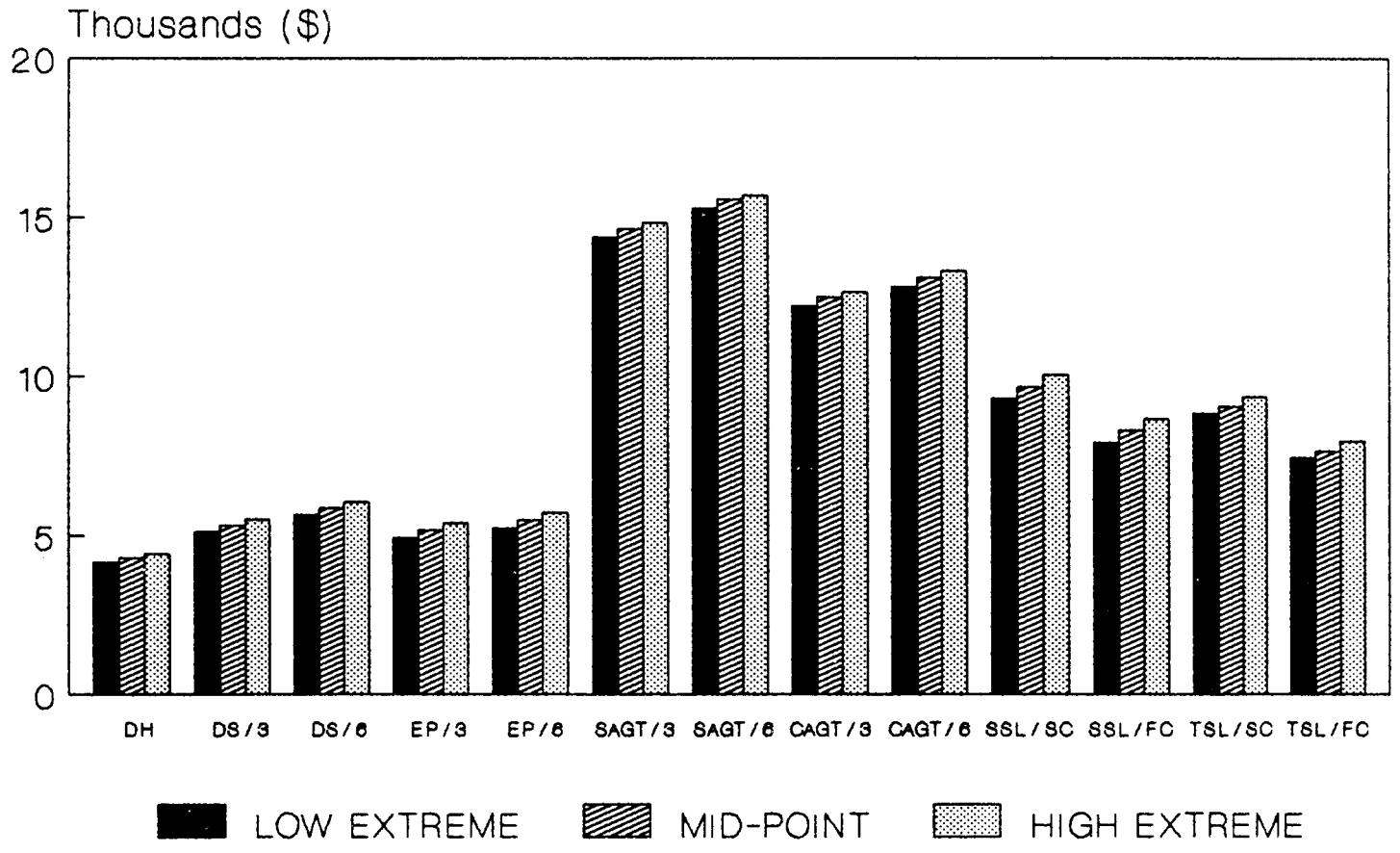
TC Systems. For waste systems modeled for herds utilizing total confinement, the greatest economies due to herd size were observed for SSL/FC systems. Per cow net annual costs fell from $96 to $20, a decline of almost 79 percent. Over the same herd size range, net annual cost per cow for the SSL/SC system declined from $119 to $35, a drop of 71 percent.

No one type of dairy waste management system exhibited a clear cost advantage over all herd sizes; i.e., the same type of system was not least cost on all herd sizes. For 80- and 160-cow herds utilizing total confinement, EP/3 systems were least cost. However, for the 320/TC herd size/confinement system, the EP/6 system had a slight cost advantage.

Among the total confinement systems, several instances of changes in relative cost advantage appeared as herd size was increased from 80 to 320 cows. For example, all lagoon systems incurred greater cost (often substantially more) than either DS system at the 80-cow herd size. However, when modeled for the 320/TC herd size/confinement system, all lagoon systems had lower costs than DS systems. The shift in cost relationship was particularly evident between the SSL/SC and DS/3 systems. At 80 cows, the SSL/SC system had a net annual cost disadvantage of $46. But, when compared at 320 cows, the SSL/SC was $13 per cow less costly.

A myriad of interrelated factors are important in determining the least cost waste system on a given herd size/confinement system. Furthermore, the relationships among these factors change, both in absolute and relative terms, as the herd size and confinement system are varied. It is obvious then, that generalities as to which system is "best" cannot be made without strict qualifications.

FIGURE 14. EFFECT ON NET ANNUAL COSTS OF 80/PC SYSTEMS WHEN NUTRIENT STORAGE LOSS RATES WERE VARIED[1]



[1]Mid-Point values were used in the base analysis (see Appendix Table 5 for ranges of nutrient loss rates).

SENSITIVITY ANALYSIS

Certain critical parameters were varied to test the stability of the results of the net annual cost analysis. Parameters deemed to be critical included manurial nutrient loss rates (during storage), value of manurial fertilizer nutrients (per unit), and labor cost (per hour).

Varying Nutrient Loss Rates (During Storage)

Nutrient losses during storage are highly variable parameters (34, 41, 43, 54, 58). A sensitivity analysis was performed to examine the effect (if any) on relative net annual costs from alteration of these parameters. Nutrient loss rates (during storage only) were varied from the lower to upper extremes of those presented in Appendix Table 5. Nutrient loss rates for N, P, and K differed for the various types of dairy waste management systems.

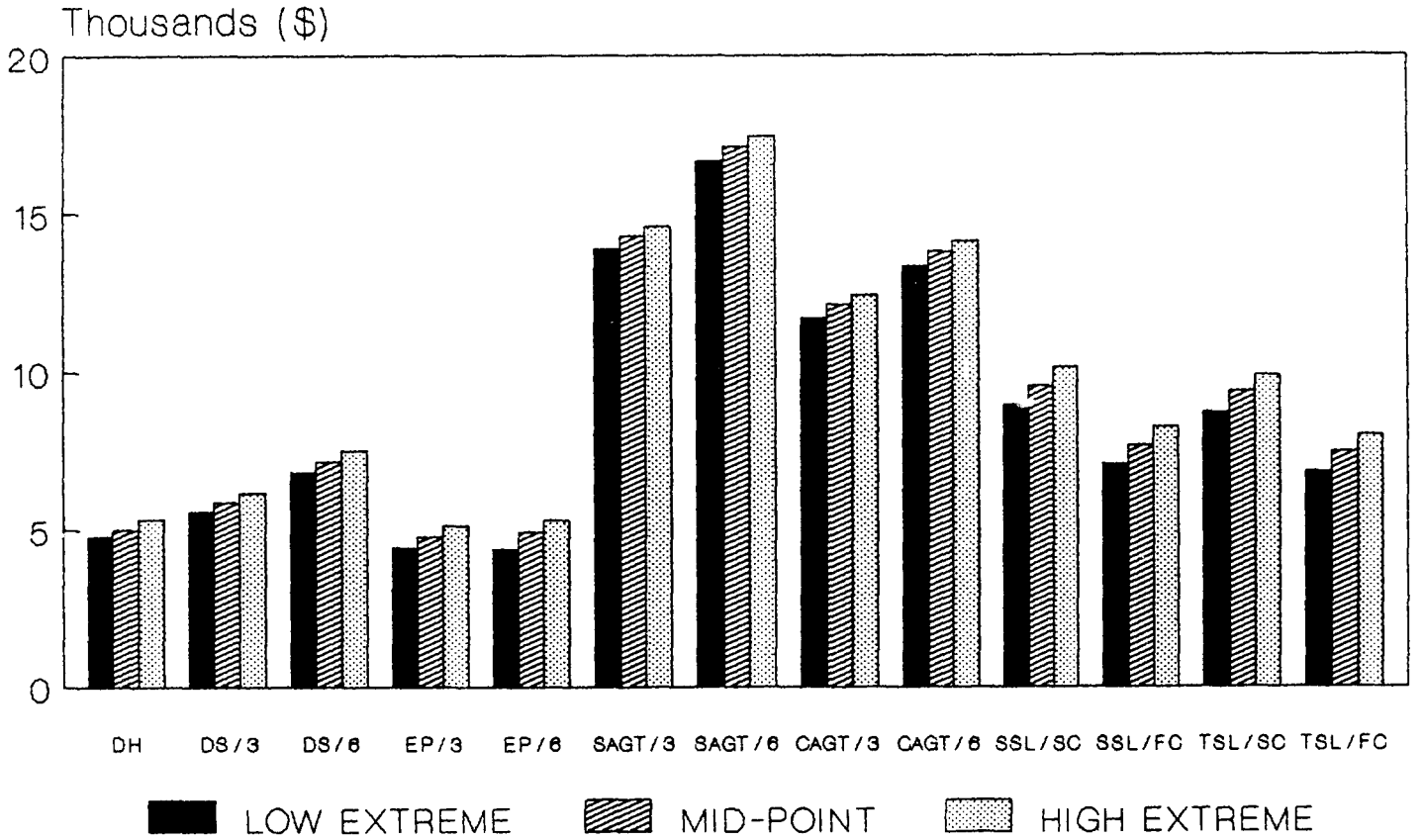
Each dairy waste management system modeled on specific herd sizes/confinement systems were compared at extreme points of storage loss rates. It was assumed that environmental conditions affected all systems similarly; i.e., if conditions existed that promoted increased nutrient loss in one system, all systems would experience increased nutrient losses. However, this may not be universally true. The possibility exists that nutrient losses may occur at the midpoint value for one system while another may experience relatively higher nutrient losses. The analysis here was to demonstrate the effect of variation in nutrient loss rates rather than to model a representative type of system. An analytical sketch of the effect of nutrient loss variation on each herd size/confinement system combination follows.

80/PC Systems

Relative net annual costs of dairy waste management systems modeled for the 80/PC herd size/confinement system were not significantly affected by varying nutrient loss rates in storage. This is evidenced by information provided in Figure 14.

Obvious (and anticipated) absolute effects on net annual costs did occur. Net annual costs for each modeled system were reduced (increased) when the respective nutrient loss rate was calculated at its lower (upper) extreme. Net annual costs were 1 to 4 percent higher at high nutrient loss levels as compared with low nutrient loss levels.

FIGURE 15. EFFECT ON NET ANNUAL COSTS OF 80/TC SYSTEMS WHEN NUTRIENT STORAGE LOSS RATES WERE VARIED[1]



[1]Mid-Point values were used in the base analysis (see Appendix Table 5 for ranges of nutrient loss rates).

80/TC Systems

No major changes in relative net annual costs resulted from varying nutrient loss rates in storage. The EP/6 system and the TSL/FC system became less costly compared to the EP/3 system and the DS/6 system respectively when storage losses were calculated at the lower extreme (Figure 15).

However, in absolute terms, net annual costs for a specific system varied by as much as $1,200 (SSL systems) from one extreme to another. In relative terms, the net annual cost for the SSL/FC system was about 17 percent higher at high as compared to low nutrient loss level assumption. Net annual cost of the EP/6 system was 21 percent higher at high as compared with low nutrient loss levels.

160/PC Systems

Variation of nutrient loss rates impacted very little upon relative net annual costs of wasted systems modeled on the 160/PC herd size/ confinement system. Indeed, system rankings were unchanged when nutrient loss rates were calculated at the lower extreme (Figure 16).

When nutrient loss rates were calculated at the upper extreme, SSL systems became more costly relative to comparable TSL systems. No other significant changes in relative net annual costs occurred.

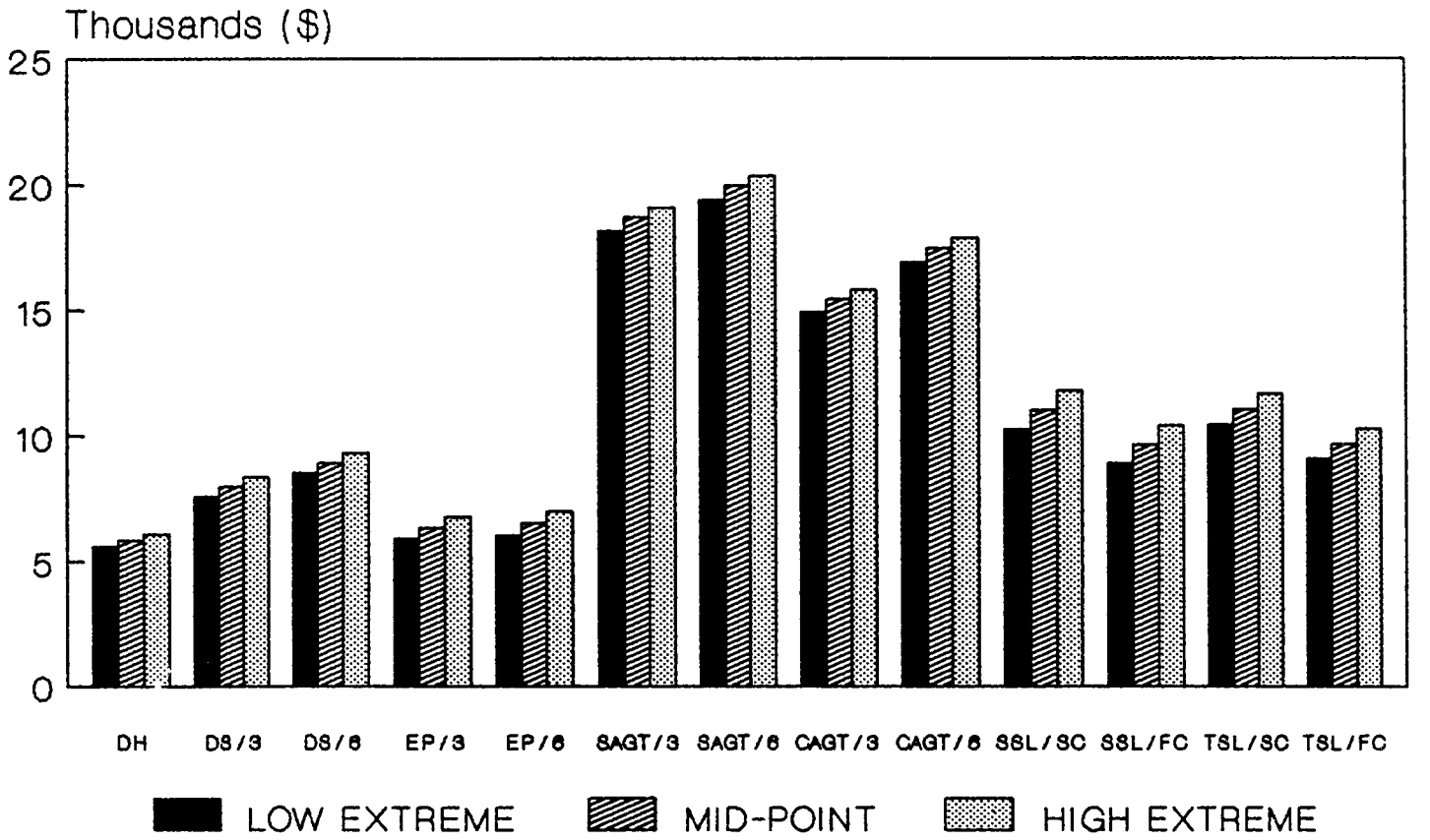
In absolute terms, net annual costs varied by as much as $1,496 (SSL systems) in response to varying nutrient loss rates. This amount represented over 15 percent of net annual cost calculated for the SSL/FC system in the base analysis. Overall, however, nutrient loss rates did not appear to impact significantly the cost rankings of the various systems.

160/TC Systems

Slightly more significant effects resulted from the sensitivity analysis on 160/TC systems. However, no system improved or regressed relative to other modeled systems by more than one position (Figure 17). Lagoon systems (SSL and TSL) improved relatively when loss rates were calculated at the lower extreme. However, the TSL/FC system also improved (relative to the base analysis) when loss rates were calculated at the upper extreme.

In absolute terms, net annual costs varied by as much as $2,385 for a given waste management system as nutrient loss rates were varied from low to high. Once again, the greatest spread occurred with the SSL systems. Net annual cost for the SSL/FC system was about 3 percent higher at high loss rates as compared to low loss rates.

FIGURE 16. EFFECT ON NET ANNUAL COSTS OF 160/PC SYSTEMS WHEN NUTRIENT STORAGE LOSS RATES WERE VARIED[1]



[1]Mid-Point values were used in the base analysis (see Appendix Table 5 for ranges of nutrient loss rates).

320/PC Systems

Relative net annual costs of dairy waste management systems modeled for the 320/PC herd size/confinement system were not significantly affected by varying nutrient loss rates (Figure 18). No system improved or regressed by more than one relative position.

Lagoon systems, especially those utilizing flush collection, appeared to become relatively less costly when nutrient loss rates were calculated at the low extreme. This advantage was lost at the upper extreme of nutrient loss rates. Indeed, at the upper extreme, the DS/6 system improved as compared with a lagoon system (SSL/SC).

With regard to absolute variation, a maximum spread of $3,070 (SSL/SC and SSL/FC systems) existed between net annual costs calculated at the lower and upper extremes. For the SSL/FC system, net annual cost was estimated to increase about 31 percent as nutrient loss rates were varied from the low to the high rate.

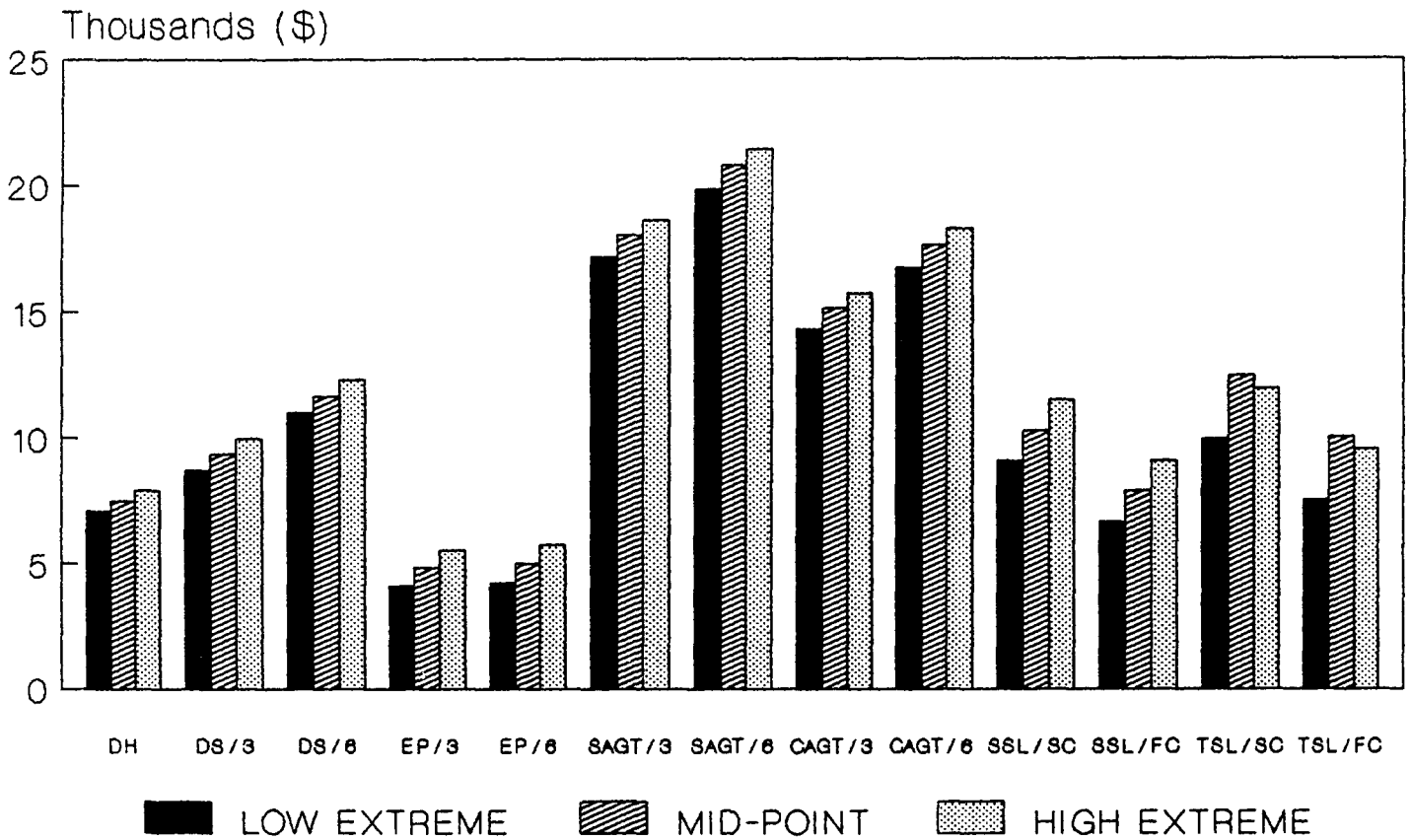
320/TC Systems

Greater impacts from varying nutrient loss rates occurred with the 320/TC systems than for other systems analyzed. Most notable was the fact that the EP/3 system improved its relative position when nutrient loss rates were calculated at the upper extreme. At the upper loss rate, the EP/3 system actually became the second least cost system, displacing the SSL/FC system. Conversely, while the EP/6 system was least cost in the base analysis, it fell to second at the lower extreme of nutrient loss rates (Figure 19).

In absolute terms, a maximum difference between net annual costs calculated at lower and upper nutrient loss rates was $4,763 and occurred for SSL systems. For the SSL/FC system, estimated net annual cost was 117 percent greater at high—as compared with low—nutrient loss rates.

For all systems considered, variations in nutrient loss rates had rather limited effect on the relative ranking of the systems in terms of net annual cost. However, net annual costs (in absolute terms) for a specific dairy waste system may be significantly affected. Differences in dollar terms were greatest on those systems designed to retain smaller proportions of manurial nutrients—SSL and TSL systems. Indeed, this result is consistent with that of the analyses on all herd sizes/confinement systems. The wider range in possible nutrient loss rates was the probable cause.

FIGURE 17. EFFECT ON NET ANNUAL COSTS OF 160/TC SYSTEMS WHEN NUTRIENT STORAGE LOSS RATES WERE VARIED[1]



[1]Mid-Point values were used in the base analysis (see Appendix Table 5 for ranges of nutrient loss rates).

Varying Nutrient Values (Prices)

As a test for sensitivity to valuation of manurial nutrients, an increase in values of 25 and 50 percent were incorporated into the analysis. Rises in value of nutrients would tend to favor waste management systems that retain larger proportions of the nutrients while in storage.

80/PC Systems

Relative net annual costs of dairy waste management systems modeled on the 80/PC herd size/confinement system were not significantly affected by increasing manurial values (Figure 20). The greatest reduction in net annual costs occurred on the SAGT/6 and CAGT/6 systems, a reduction of $1,828 or almost 14 percent of net annual cost calculated in the base analysis for the CAGT/6 system.

80/TC Systems

Relative net annual costs of modeled dairy waste management systems were not significantly affected by increases in manurial nutrient values (Figure 21). The major change was the EP/6 system becoming the least cost system at both the 25 and 50 percent valuation adjustment levels (instead of EP/3). For the base analysis, the EP/6 system had ranked second. Only $19 separated the EP/6 system from the next least cost system (EP/3). The only other change in system rankings occurred at the 50 percent adjustment level.

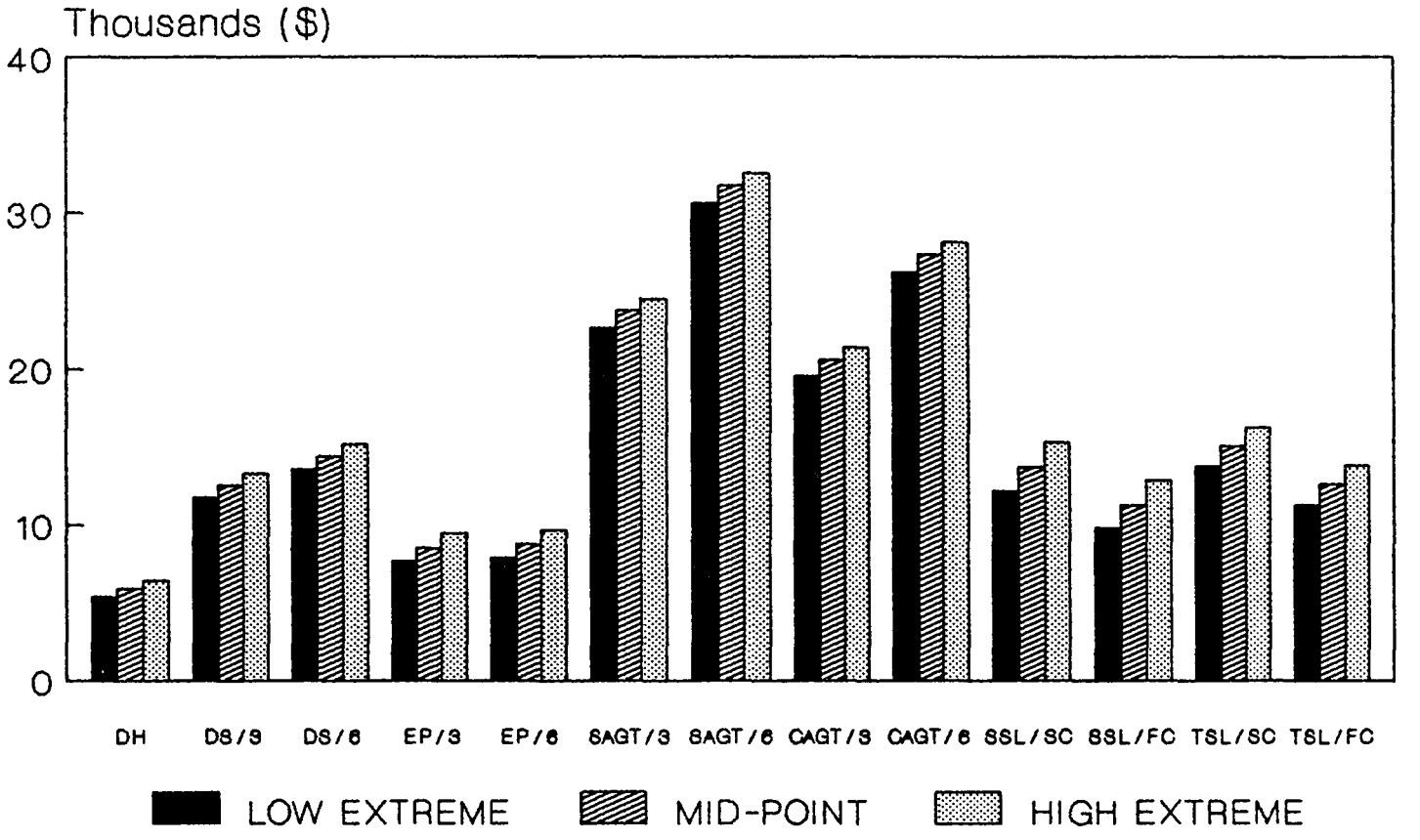
With regard to absolute costs, the most significant reduction in net annual costs was $2,939 on SAGT/6 and CAGT/6 systems. This amount represented a reduction of over 24 percent of the net annual cost as compared to the base analysis for the CAGT/6 system.

160/PC Systems

Increases in manurial nutrient values affected relative net annual costs of waste systems modeled for the 160/PC herd size/confinement system only slightly (Figure 22). The DH system fell from first (least cost) to third as manurial fertilizer value was increased by 25 and 50 percent. The EP/3 system was the least cost system when nutrient values were increased by 25 and 50 percent above the base levels.

Net annual costs declined, in absolute terms, when nutrient values were increased for each waste system. When nutrient values were increased by 50 percent, the greatest decline ($3,612) was for the SAGT/6 and CAGT/6 systems. Net annual cost for the CAGT/6 system was

FIGURE 18. EFFECT ON NET ANNUAL COSTS OF 320/PC SYSTEMS WHEN NUTRIENT STORAGE LOSS RATES WERE VARIED[1]



[1]Mid-Point values were used in the base analysis (see Appendix Table 5 for ranges of nutrient loss rates).

reduced 26 percent as result of the 50 percent increase in manure nutrient value.

160/TC Systems

Relative net annual costs of dairy waste management systems modeled on the 160/TC herd size/confinement system were somewhat sensitive to increases in manurial nutrient values (Figure 23). DH fell in rank from third to fourth, and the EP/3 system fell from first to second as nutrient values increased by 50 percent. However, both SSL systems and the EP/6 system became less costly, in relative terms, over the same value variation. The EP/6 system was ranked as least cost when nutrient values were increased by 50 percent.

Positive annual returns to waste management systems were calculated for the first time in this study when nutrient values was increased by 50 percent. These positive returns (negative net annual costs) accrued to both the EP/3 and EP/6 systems.

In absolute terms, net annual costs fell as much as $5,847 when manurial nutrients rose in value. The greatest decline occurred on the SAGT/6 and CAGT/6 systems; a reduction of over 33 percent of the "base" net annual cost was indicated (CAGT/6 system).

320/PC Systems

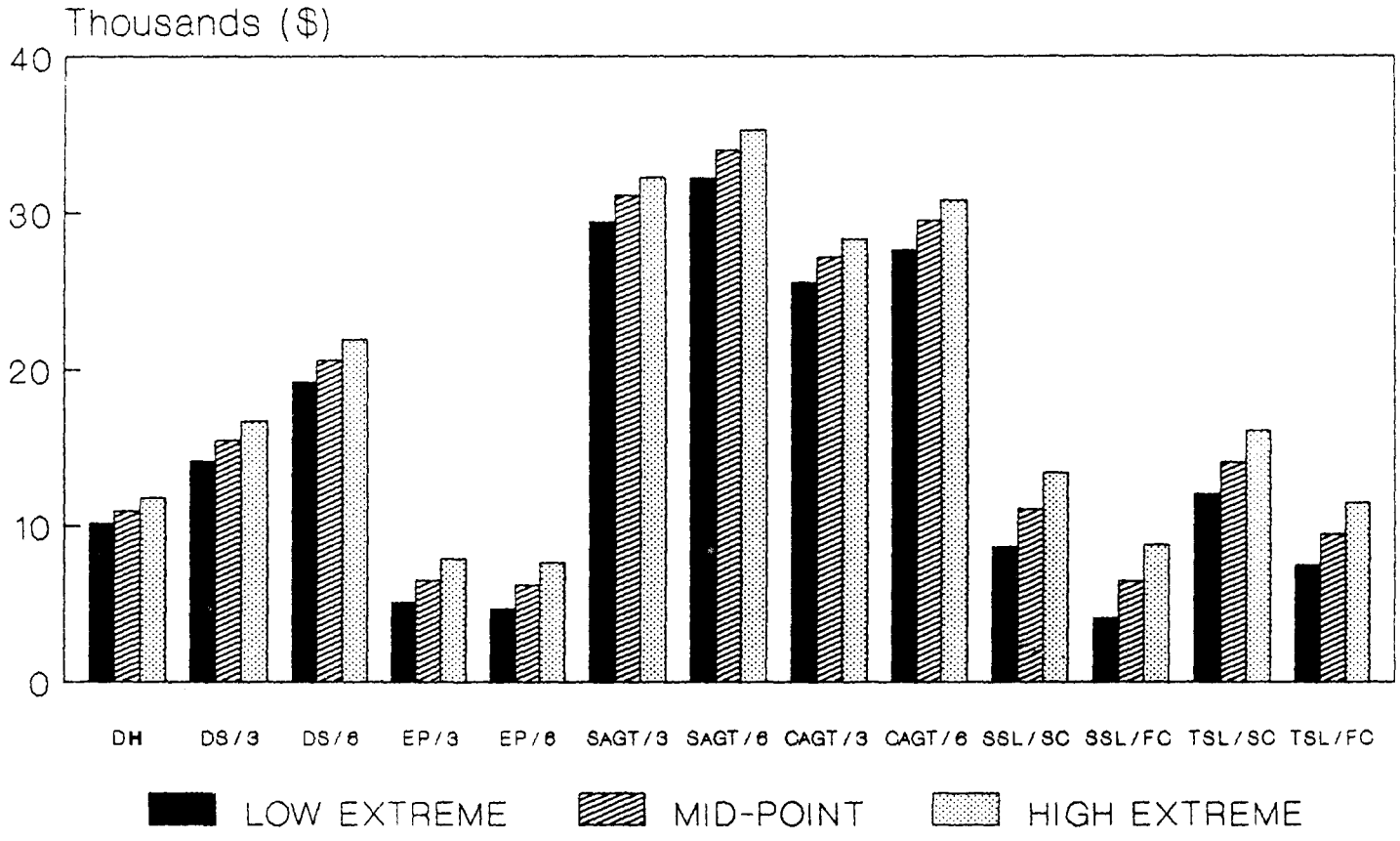
Relative net annual costs of dairy waste management systems modeled on the 320/PC herd management system were affected slightly by increasing manurial nutrient values (Figure 24). The DH system became relatively more costly as nutrient values increased by 50 percent. Indeed, the DH system fell from first to third. Conversely, the EP/6 became relatively less costly over the same range. The EP/6 system became least cost at the upper level of nutrient valuation.

Increasing manurial nutrient values by 50 percent resulted in a decline of net annual costs of as much as $7,211 (the SAGT/6 and CAGT/6 systems). For the CAGT/6 system, this represented a reduction of more than 26 percent of net annual cost compared to the base analysis.

320/TC Systems

Relative net annual costs of dairy waste management systems modeled on the 320/TC herd size/confinement system were not affected significantly by increases in manurial fertilizer nutrient values (Figure 25). The DH, SSL/FC and EP/3 systems became more costly relative to other systems as nutrient values increased by 25 and 50

FIGURE 19. EFFECT ON NET ANNUAL COSTS OF 320/TC SYSTEMS WHEN NUTRIENT STORAGE LOSS RATES WERE VARIED[1]



[1]Mid-Point values were used in the base analysis (see Appendix Table 5 for ranges of nutrient loss rates).

percent. Conversely, the EP/6 system and both SSL/SC systems improved relatively over the same range. The EP/6 system, ranked third in the base analysis, became the least-cost system. The SSL/SC system, which had been the least costly, rose to fifth.

Three waste systems, EP/3, EP/6, and SSL/FC, incurred negative net annual costs (positive returns) when manurial nutrients were valued 50 percent above current market prices. Obviously, manurial nutrient values would need to rise considerably before waste management systems would appear to be lucrative based solely on an investment analysis.

An increase in manurial fertilizer value by 50 percent resulted in a reduction in net annual costs as much as $11,688 (SAGT/6 and CAGT/6 systems). For the CAGT/6 system, this translated to a reduction of almost 40 percent of net annual cost calculated for the base analysis.

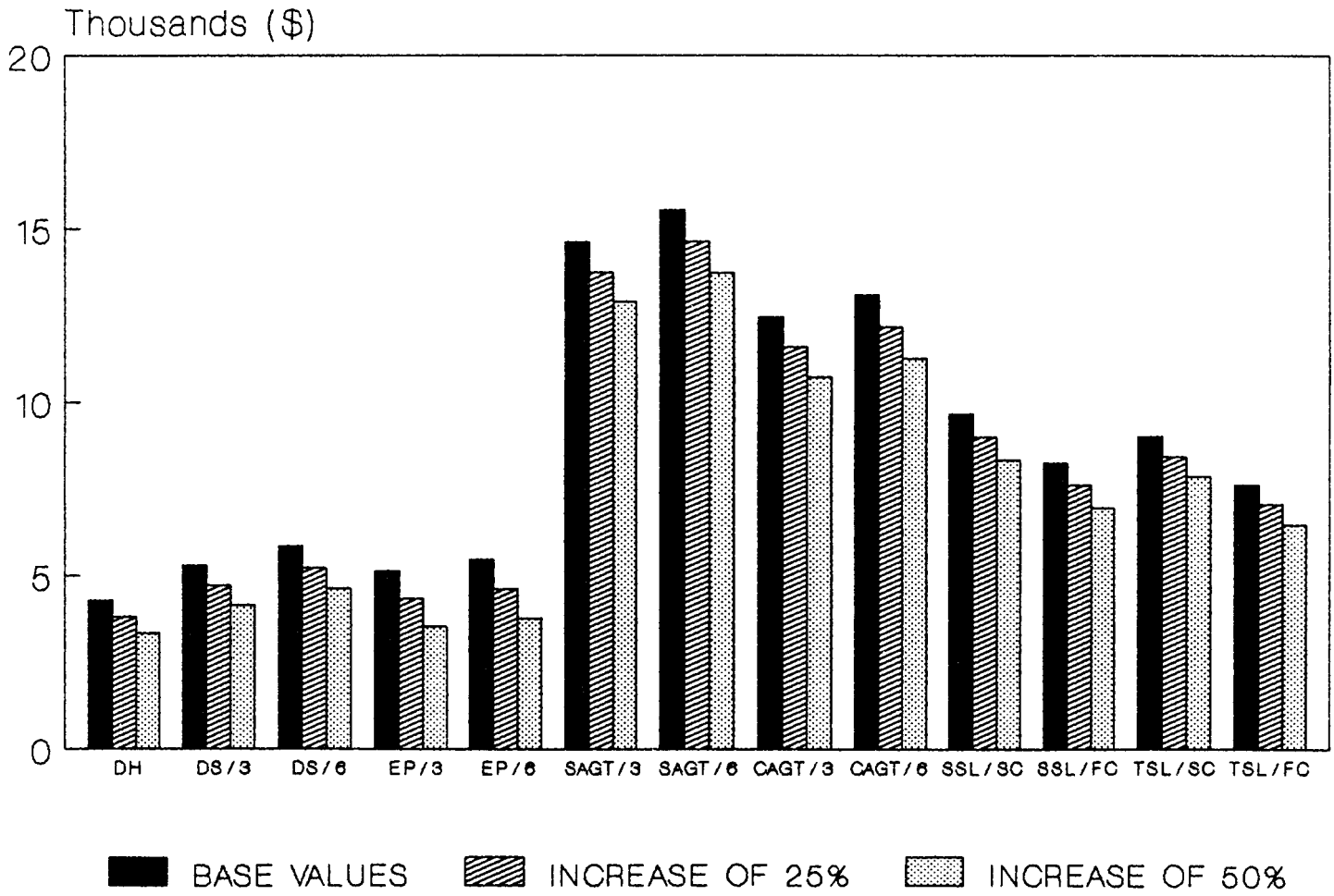
Varying Labor Costs (Hourly)

Dairy waste management systems are typically considered to be labor intensive. Variations in opportunity costs of labor could therefore have an impact upon the choice of system installed. To test for possible sensitivity to this parameter, labor costs were increased and decreased by 40 percent from the base rate of $5 per hour on each modeled dairy waste management system. This method was adopted as a proxy for a more complete and detailed analysis. Opportunity costs of labor vary according to season, labor restrictions, environmental conditions, as well as quality. However, these factors are predominantly farm-specific and thus could not be incorporated adequately into a general analysis.

Obviously, the impact on the more labor intensive systems was greater in absolute terms. The greatest absolute change in net annual cost for any specific dairy waste system was $2,508. For the 320/TC/DH system, increasing (decreasing) the labor cost by 40 percent would increase (decrease) the net annual cost about 23 percent.

In relative terms, for all herd sizes/confinement systems, little significant effect of the changes in cost of labor was observed. However, although the variations in labor costs were considered major (+ or — 40 percent), opportunity costs of labor are likely to vary over a wider range during the course of a year. Opportunity costs of labor on a given farm depend on absolute restrictions on labor available, degree of competition for labor particularly during planting and harvesting seasons, climatic conditions,

FIGURE 20. EFFECT ON NET ANNUAL COSTS OF 80/PC SYSTEMS WHEN MANURIAL NUTRIENT VALUES WERE INCREASED 25 AND 50 PERCENT



and quality of labor assigned to waste management. A more accurate determination of appropriate cost of labor would necesarily include data that is farm-specific, e.g., seasonal demands of labor for various farm uses.

SUMMARY AND CONCLUSION

Purpose and Procedure

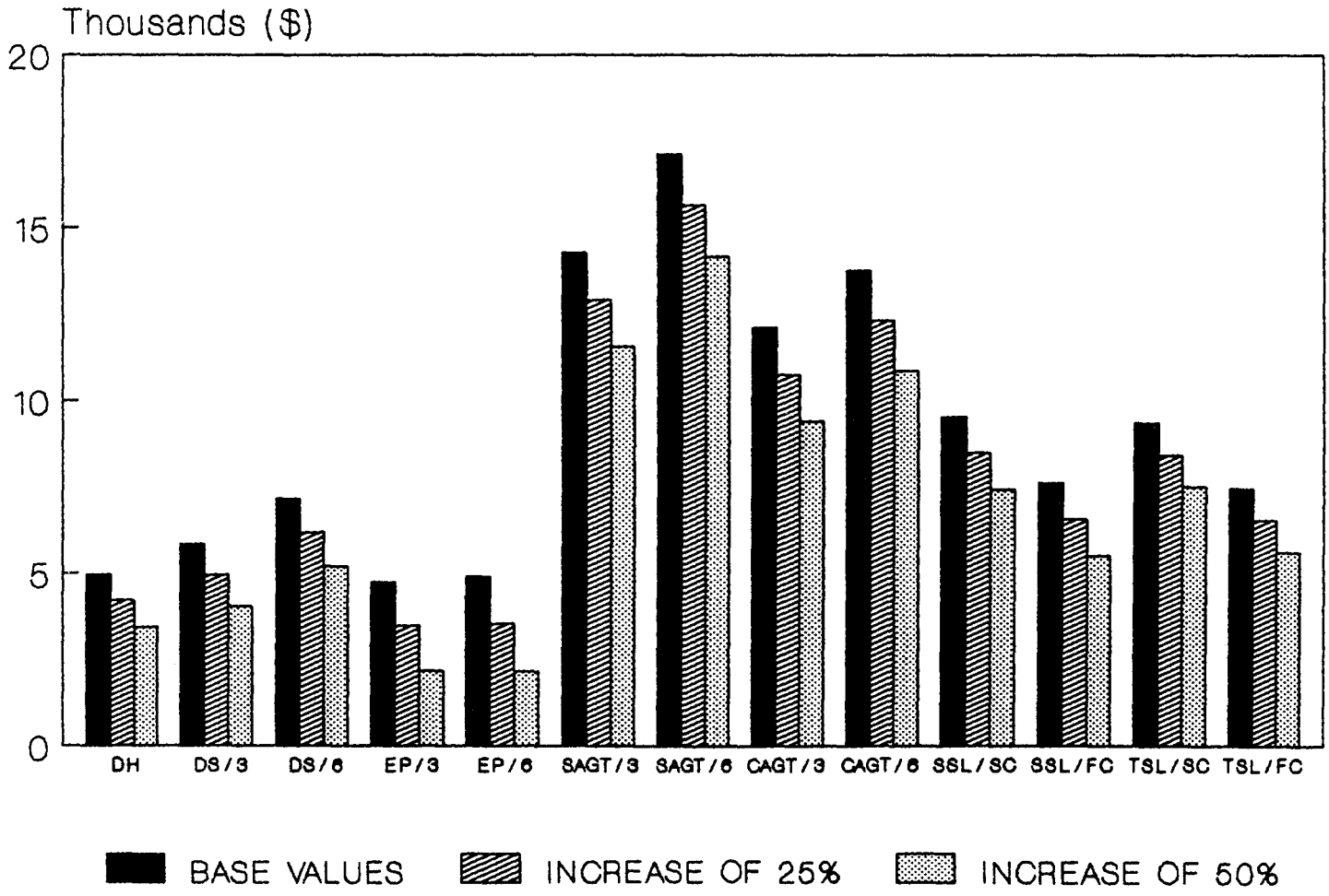
The purpose of this research was to make a comparative evaluation of the various waste management systems most commonly found on Tennessee dairy farms. Systems deemed to be most typical were classified as: (1) daily haul (DH), (2) dry stack (DS), (3) earthen pit (EP), (4) aboveground tank (AGT) (steel or concrete), (5) single-stage lagoon (SSL), and (6) two-stage lagoon (TSL). Three- and six-month storage capacities were studied for DS, EP, and AGT systems.

The dairy waste management systems were compared for various sizes of milking herds and alternative confinement systems. The sizes of milking herds modeled were 80, 160, and 320 cows. Alternative confinement systems were defined as partial and total confinement. Seventy-eight distinct dairy waste systems resulted from incorporating the three herd sizes, two confinement systems, and seven waste systems (with associated variation in storage capacity and collection methods) into the analysis.

Selection of dairy waste management systems (and variations of these systems) to include in this study was based primarily upon interviews with East Tennessee dairy farmers and U. S. Department of Agriculture Soil Conservation Service personnel. Each specific system (determined by herd size, confinement system and waste handling/storage method) was modeled in technical detail with regard to: (1) quantities of waste nutrients preserved through the collection, storage, and land application processes; (2) labor and tractor/equipment requirements for the various tasks involved; (3) mineralization of waste nutrients after land application.

The modeling process was effected through the development of budgets for the various technical and economic aspects of dairy waste management. The purely technical budgets outlined physical changes that occur as dairy

FIGURE 21. EFFECT ON NET ANNUAL COSTS OF 80/TC SYSTEMS WHEN MANURIAL NUTRIENT VALUES WERE INCREASED 25 AND 50 PERCENT



waste moves through the respective collection, storage, and disposal subprocesses of each waste management system. Purely technical budgets included: (1) Collection Budgets and (2) Storage and Application Budgets.

Budgets were also developed that included both technical and economic data. Essentially, the economic data presented involved valuation of synthesized technical data. These hybrid budgets were the following: (1) Annual Labor and Energy Cost Budgets and (2) Nutrient Mineralization and Annual Valuation Budgets.

Purely economic budgets were likewise constructed. Data for these budgets came from the hybrid budgets and other synthesized economic data. Economic budgets included: (1) Initial Investment Budgets, (2) Capital Recovery and Insurance/Repairs/Housing Costs Budgets, and (3) Net Annual Cost Budgets.

Based upon this synthesized technical data and primary cost data collected, initial investment and annual costs/returns estimates were made for each specific dairy waste management system. Estimates of quantifiable economic returns from any system were restricted to the fertilizer value of the waste nutrients preserved by that waste system.

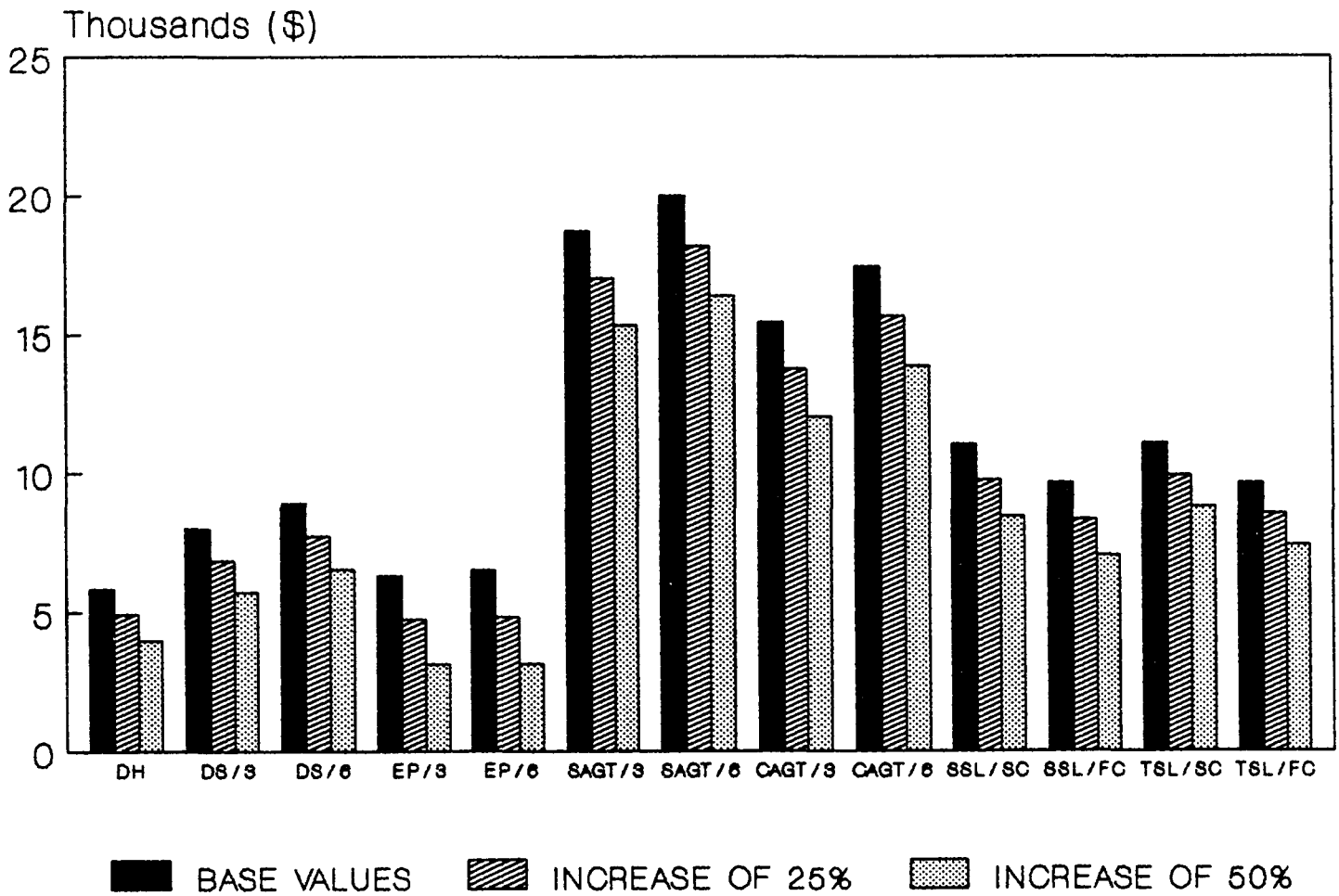
Analysis of Modeled Systems

Economic comparisons of modeled dairy waste management systems were based upon both initial investment and net annual costs. Because of debt load, cash flow considerations or ability to handle risk, a dairy farm manager might opt for a waste management system that requires the least initial capital outlay even though this system may not be the most economically efficient system in the long run. Net annual cost is probably the most common basis for comparison in economic analysis. Net annual cost was computed as the difference between total annualized cost of the waste management system less the value of the fertilizer nutrients retained.

Initial Investment

Dairy waste management systems were compared, with initial investment as the criteria, on each herd size and confinement system. Only equipment/facilities predominantly used for waste management were included. These items would most likely need to be purchased in order to install the particular waste system. Items, such as tractors used for hauling/spreading, agitation, and irri-

FIGURE 22. EFFECT ON NET ANNUAL COSTS OF 160/PC SYSTEMS WHEN MANURIAL NUTRIENT VALUES WERE INCREASED 25 AND 50 PERCENT



gation, were assumed to be on the dairy farm prior to installation of a particular dairy waste system.

In each case (specific herd size/confinement system) analyzed, the DH system required the lowest initial investment. Generally EP (particularly EP/3) systems were the next lowest investment systems. The difference between the least cost and next least cost systems was often substantial. The greatest difference (320/TC analysis) was 69 percent; the narrowest margin was 27 percent (80/PC analysis).

AGT systems consistently required the greatest investment cost. SAGT systems required larger capital outlays than similar CAGT systems.

DS systems typically required greater initial investment than EP systems and less investment than lagoon systems (TSL and SSL). However, TSL and SSL systems were quite competitive with alternative systems for 320-cow herds. Lagoon systems required significantly less capital outlay than the DS/6 system on the 320/TC herd size/confinement system. In addition, lagoon systems incorporating flush collection generally were cheaper to install than similar systems using standard collection methods.

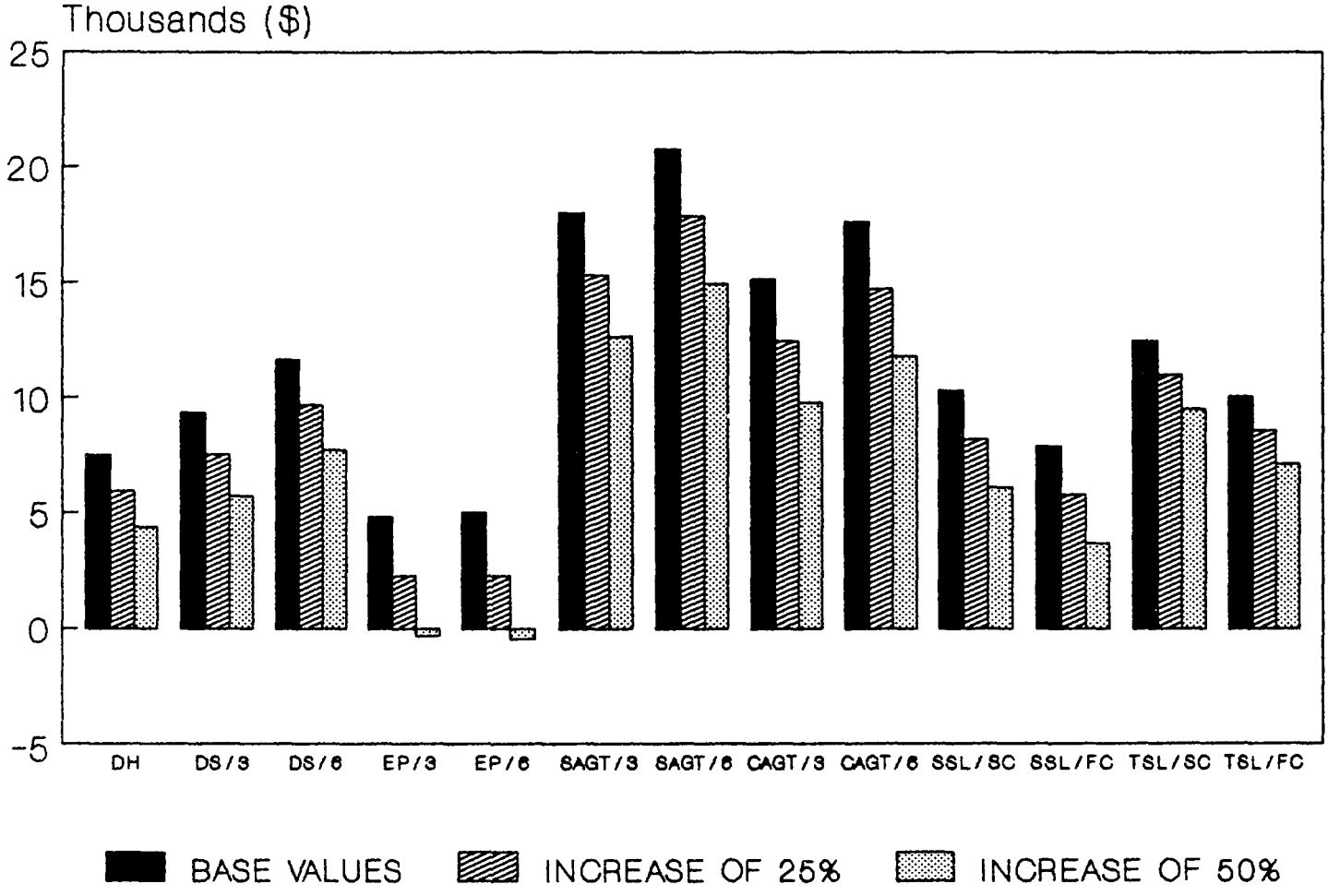
Definite economies of herd size were evident. Per-cow investment costs of DH systems fell by almost 70 percent as herd size was increased from 80 to 320 cows. Similar economies, albeit of smaller magnitude, occurred on all waste management system types. The smallest decline in initial investment costs per cow as herd size was increased from 80 to 320 cows occurred on TC/DS/6 systems (36.3 percent).

For those systems in which storage capacity was varied, doubling storage capacity resulted in considerably less than double initial investment cost. Therefore, strictly from an analysis of initial capital outlay, purchasing additional capacity appeared to be a "bargain." However, based on an analysis of net annual costs, this observation was not necessarily true.

Net Annual Costs

Dairy waste management systems were also compared on each modeled herd size/confinement system with net annual cost as the criterion. Unlike the initial investment analysis, all equipment/facilities used on specific dairy waste management systems were included in net annual

FIGURE 23. EFFECT ON NET ANNUAL COSTS OF 160/TC SYSTEMS WHEN MANURIAL NUTRIENT VALUES WERE INCREASED 25 AND 50 PERCENT



cost analysis. Equipment not predominantly used in dairy waste management (e.g., tractors used for hauling wastes) was included also. Annualized equipment/facilities costs were prorated based upon estimates of proportionate annual use allocated to dairy waste management.

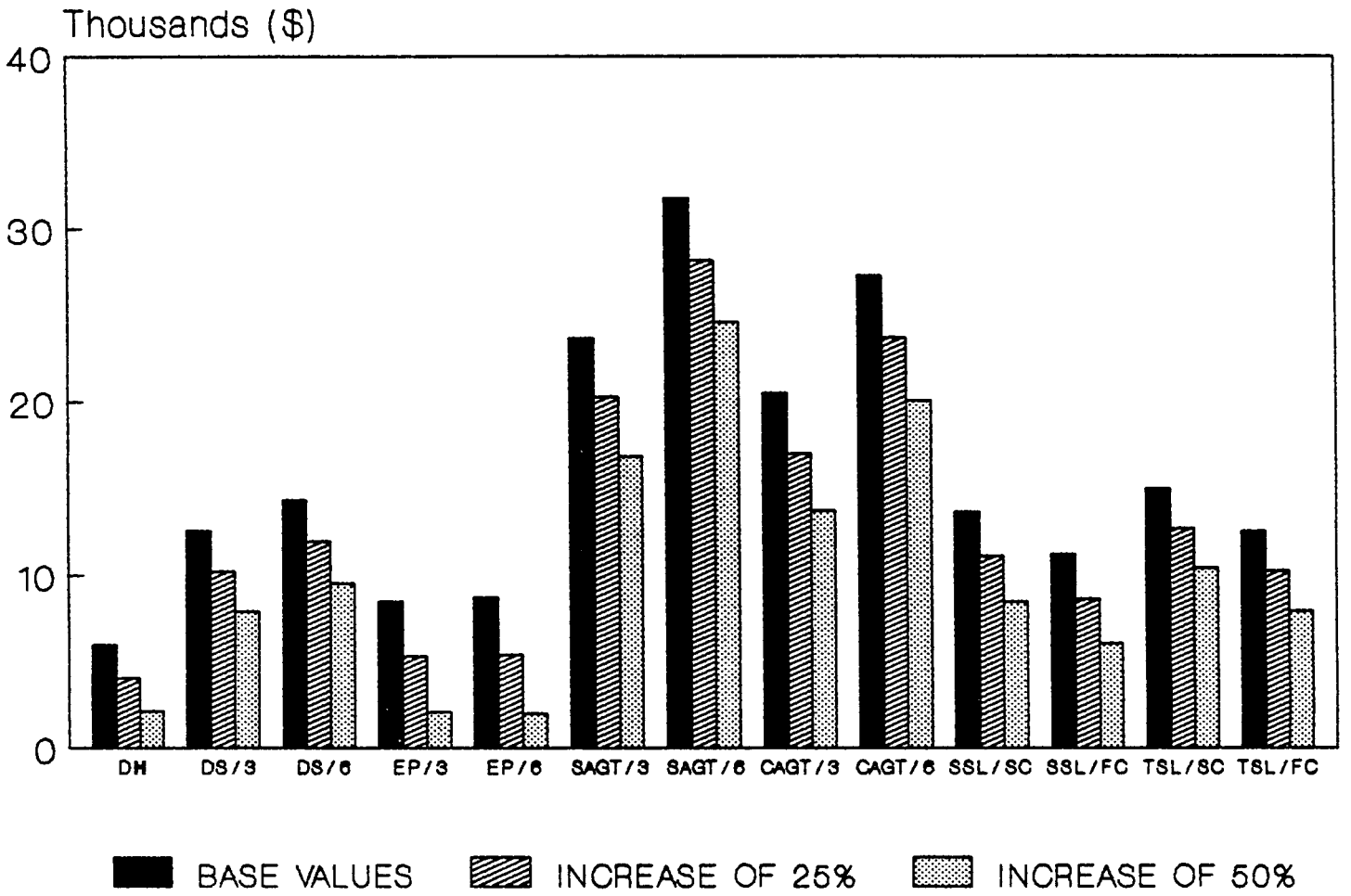
Net annual cost for each system was calculated as follows: Capital recovery plus insurance/repairs/housing costs plus annual equipment rental cost plus energy costs plus labor costs minus annual fertilizer value of dairy wastes. Capital recovery was calculated for equipment/facilities specific to each system. Since calculation of capital recovery depended upon the life of the asset, life expectancies were estimated for all equipment/facilities. Current market interest rates were used.

Annual costs of insurance, repairs or maintenance, and housing were approximated for components of each waste system. Annual equipment rental costs occurred only on TSL systems. These costs were, in fact, incurred at five-year intervals (sludge removal). Annual equipment costs incurred during these years were present valued to year one; the sum of these costs were then annualized over the life of the system.

Labor and energy requirements for each dairy waste management system were synthesized for each budget (two-month) period. Associated costs were also calculated and summed by budget period. Budget period totals were summed to determine annual labor and energy costs incurred with each waste management system. In the case of nonannual tasks, such as sludge removal from TSL systems, costs of completing these tasks in each year of occurrence were first discounted to year one and summed. This total present value of costs was then annualized over the life of the waste system and added to reflect "real" annual labor and energy costs.

Annual fertilizer value of dairy wastes could be made only after accounting for nutrient losses during collection, storage, and application. These nutrient losses were modeled in the Collection Budgets and Storage and Application Budgets. However, nutrients incorporated into the soil are not 100 percent available to crops during the first year after land application. Rather, waste nutrients are mineralized (over several years) into inorganic forms

FIGURE 24. EFFECT ON NET ANNUAL COSTS OF 320/PC SYSTEMS WHEN MANURIAL NUTRIENT VALUES WERE INCREASED 25 AND 50 PERCENT



that are available for crop uptake. Budgets were developed to model this mineralization process and determine the annual value of nutrients applied with each waste management system. Although it is generally recognized that animal manure contains inherent value as a soil enhancement (tilth and organic matter), these factors cannot be easily quantified and were not included in the analysis.

Net annual cost was the primary economic parameter used in comparing modeled dairy waste management systems. All the various aspects of waste handling systems were netted out in this calculation, providing one number per system that could be used as a comparative tool. It was this figure, more than any other, that determined which waste system (and variation of that system) was most "economical."

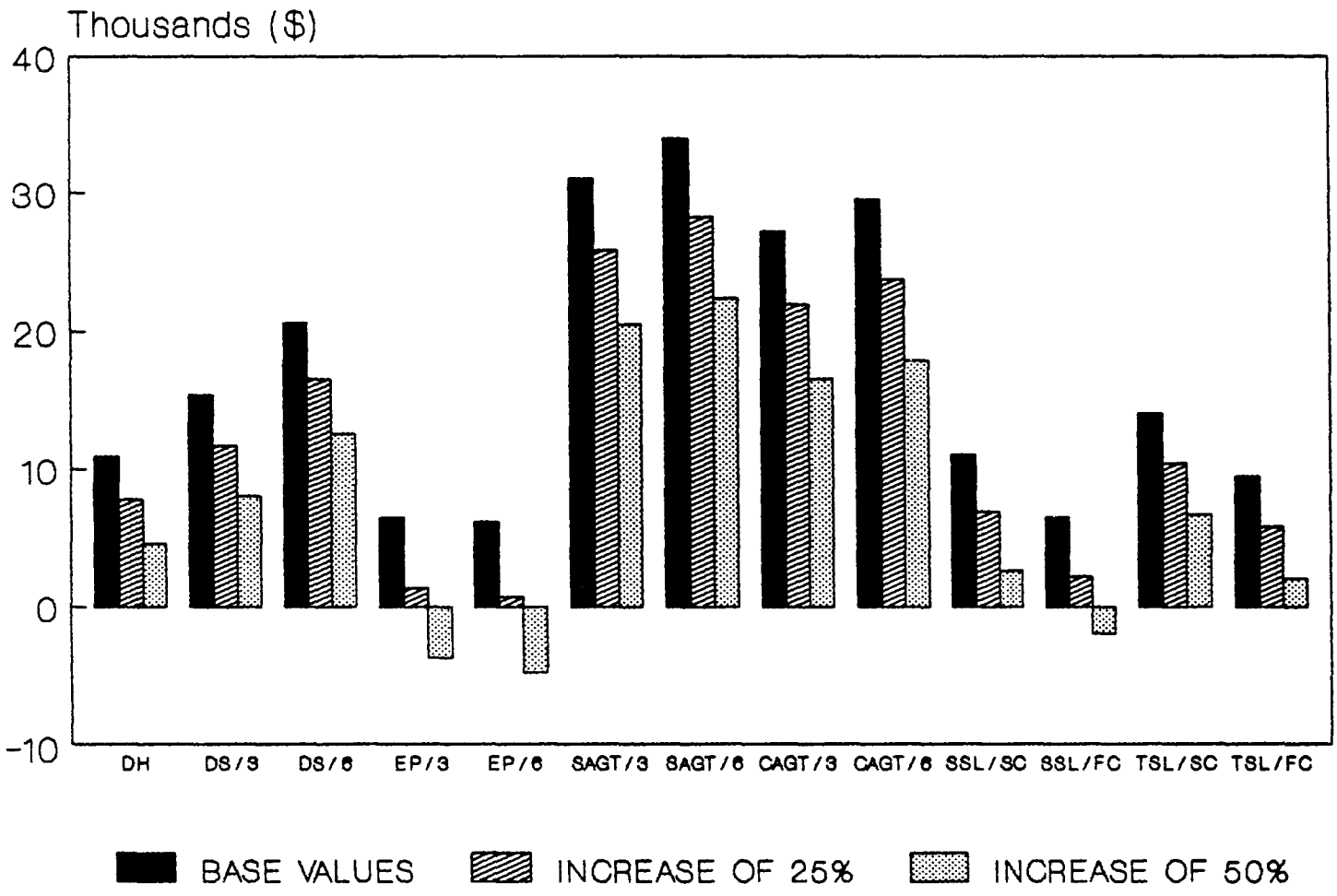
No one system dominated other modeled systems (with regard to being the least net annual cost system) consistently as herd size and/or confinement system varied. Generally, however, the DH system was least cost for herd sizes utilizing partial confinement. On herds using total confinement, DH tied for the second least cost system at best. EP (EP/3 and EP/6) systems tended to be least cost on modeled dairy herds incorporating total confinement. However, lagoon systems, especially the SSL/FC system, became quite competitive at the 320-cow herd size. On the modeled 320/TC herd size/confinement system, the SSL/FC system cost only $1 per cow more annually than the least cost waste system (EP/6).

AGT systems, specifically SAGT systems, were consistently the most costly systems, and by a significant margin. At no herd size/confinement system did AGT systems even become competitive. In some cases, an SAGT system cost more than $100 per cow more annually than the corresponding least cost system.

Increasing storage capacity reduced net annual costs only for EP systems. Modeled EP/3 systems incurred lower net annual cost than EP/6 systems in all but one instance (on the 320/TC system). However, no more than $3 per cow per year separated the two EP systems in any instance.

Significant economies of herd size were incurred on all

FIGURE 25. EFFECT ON NET ANNUAL COSTS OF 320/TC SYSTEMS WHEN MANURIAL NUTRIENT VALUES WERE INCREASED 25 AND 50 PERCENT



modeled waste systems. However, the greatest economies of size tended to accrue to SSL, TSL, and EP systems (especially when total confinement was used).

Sensitivity Analysis

Certain critical parameters were varied to test the stability of the results of the net annual cost analysis. Parameters deemed to be critical included manurial nutrient loss rates, manurial nutrient value (per unit), and labor cost (per hour).

Varying Nutrient Loss Rates (During Storage)

Nutrient losses during storage are highly variable. A sensitivity analysis was performed to observe the effect on relative net annual costs due to alteration of these parameters. Nutrient loss rates (during storage) were varied from the lower to upper extreme of ranges commonly reported.

In general, variation of nutrient loss rates did not impact significantly on relative net annual costs. The relative ranking of systems were not greatly affected. However, net annual costs for a particular dairy waste system was significantly affected, in some cases, in absolute terms. Significant effects on relative net annual costs may occur if nutrient losses for the different systems were impacted differently by environmental conditions.

Varying Nutrient Values (Prices)

To test for sensitivity to valuation of manurial nutrients, the effect of an increase in nutrient values of 25 and 50 percent were analyzed. This test was also conducted to observe at what level of nutrient valuation would positive returns (negative net annual costs) accrue to any of the systems.

Generally, increases in manurial nutrient values did not significantly affect relative net annual costs of systems modeled for the 80-cow herd size. However, as herd size increased, greater impact was evident, especially on systems associated with total confinement.

DH systems (nutrient inefficient systems) generally were impacted unfavorably; nutrient-saving systems were generally affected the most favorably. DS systems were often affected adversely.

Only when nutrient values were increased by 50 per-

cent, and on 320/TC systems, did positive returns accrue to any dairy waste management system. Increases of this magnitude in prices of manurial fertilizer nutrients exceed commonly held price expectations for the near future.

Varying Labor Costs (Hourly)

Dairy waste management systems are typically considered to be labor intensive. Variations in opportunity costs of labor may therefore impact upon the choice of an optimal dairy waste system. Labor costs were varied by ±40 percent on each modeled dairy waste management system to test for possible sensitivity to this parameter. This technique was used as a proxy for a more detailed and complete analysis of labor value variation. Opportunity costs of labor vary according to seasonal labor constraints, environmental conditions, as well as quality of labor assigned to waste management. However, these factors are predominantly farm-specific and thus cannot adequately be incorporated into a general analysis.

Relative net annual costs of modeled dairy waste management systems were not acutely sensitive, generally, to even substantial changes in labor costs. Obviously, the more labor intensive systems were impacted greater in absolute terms. Indeed, a 23 percent change in net annual cost was effected for the 320/TC/DH system due to the variation in labor cost. However, in relative terms, labor cost variation did not impact net annual costs as greatly as was perhaps anticipated.

Implications for the Dairy Industry

Results of this study tend to support the notion that significant economies of herd size are evident on U. S. dairy farms. Although waste management system costs may not represent a majority of total annual costs for individual dairy farms, these costs are likely to be significant. Reduction in average total costs on dairy farm firms attributable to economies of herd size with regard to waste management provides further incentive for increases in dairy herd size.

Additionally, imposition of stringent environmental regulations on the dairy farm sector could impact significantly upon individual dairy farm firms and the dairy industry. Because waste management on dairy farms is a costly process, increased regulations would result in increases in total costs for the dairy industry (on individual farms and in the aggregate).

Implications for Further Research

Although this study included the most typical types of dairy waste management systems found in Tennessee dairy farms, similar research should perhaps be conducted for less-than-typical systems. Dairy waste technology, only recently proven technically feasible or acceptable, could be included. Examples include methane generation, solids-liquids separation, refeeding, and using dried wastes as bedding. Through the development of budgets and economic research, these waste management systems could be evaluated relative to alternative methods and techniques.

Analyses such as this study, in which economic modeling is the foundation, can potentially be developed within a mathematical programming framework. Considerably more technically-detailed and accurate models could thereby be compiled. Greater numbers of alterations in the base model (sensitivity analysis) could be performed to test the model more fully. In addition, with the advent and more widespread use of microcomputers, such a model would potentially be developed as a decision aid for dairy farmers.

However, in order for mathematical programming models to be effective tools, considerable technical research is needed. More complete data on nutrient losses during storage (and interrelationships with environmental parameters), nutrient losses after application (in a format conducive to modeling), and nutrient utilization (e.g., uptake by pasture vegetation as opposed to side-dressed corn) are required.

Dynamic modeling is also needed to incorporate the entire dairy farm firm for completeness. Upper limits on the amount of labor available and degree of competition for labor for other farm tasks are important aspects in determining the "real" or opportunity cost of labor used for waste management. Incorporating these considerations into a mathematical, computerized model would aid in providing more precise estimates of the most economical dairy waste management system for a given dairy farm setting.

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APPENDICES

Table 1. Daily Manure Production by Dairy Cattle[a]

Size lbs	Total Manure Production lb/day	ft^2/day	gal/day	Water %	Density lb/ft^3	Nutrient Content (#/day) N	P	K
150	12	0.19	1.5	87.3	62	0.06	0.010	0.04
250	20	0.32	2.4	87.3	62	0.10	0.020	0.07
500	41	0.66	5.0	87.3	62	0.20	0.036	0.14
1 000	82	1.32	9.9	87.3	62	0.41	0.073	0.27
1 400	115	1.85	13.9	87.3	62	0.57	0.102	0.38

[a]Midwest Plan Service (41).

Table 2. Assumed Percentage of Herd Time Spent on Feeding/Housing Lots by Waste Production Period and Confinement System

Confinement System	Waste Production Period	Percent of Herd Time Spent on Feeding/Housing Lots
Partial confinement	Jan.-Feb.	80
	March-April	65
	May-June	45
	July-Aug.	45
	Sept.-Oct.	45
	Nov.-Dec.	65
Total confinement	Jan.-Feb.	95
	March-April	95
	May-June	90
	July-Aug.	90
	Sept.-Oct.	90
	Nov.-Dec.	95

Table 3. Daily Production of Milking Parlor Wastes by Herd Sizes[a]

Parlor Waste Source	Daily Waste Production (gal.) 80 Cows	160 Cows	320 Cows
Bulk tank	25	27.5	30
Pipeline	150	160	200
Udder wash	40	80	320
Parlor floor	40	50	70
Milkhouse floor	10	15	20
Miscellaneous	30	30	30
Total	295 (2,463.25 lbs)	362.5 (3,026.88 lbs)	670 (5,594.501 lbs)
Nutrient production lbs/day			
N	0.6158	0.7560	1.3985
P	0.3658	0.4490	0.8307
K	0.4543	0.5583	1.0318

[a]Adapted from 5, 38, 40, 41, and 73.

Table 4. Mean Monthly Precipitation and Evapotranspiration Rates Used for the Analysis[a]

Climatic Month	Mean Monthly Precipitation (inches)	Mean Monthly Evapotranspiration (inches)
January	5.33	0.2818
February	4.97	0.4014
March	5.46	1.0564
April	4.35	2.2032
May	3.94	3.4300
June	3.89	4.5100
July	4.48	5.2700
August	3.55	5.1100
September	3.16	3.9300
October	2.62	2.3600
November	3.82	0.9662
December	4.56	0.3700
Yearly totals	50.13	29.89

[a]Calculated from data presented in 16 and 62.

Table 5. Estimated Nutrient Loss During Storage (Prior to Land Application) from Various Dairy Waste Management Systems[a]

Category/System	Estimated Nutrient Loss (%)		
	N	P	K
Solid/			
Daily haul	30-40	5-15	5-15
Dry stack	15-30	5-20	5-15
Slurry/			
Aboveground tank	5-20	0-10	
Earthen pit	15-25	5-20	5-15
Liquid/			
Two-stage lagoon	60-80	50-65	35-50
Single-stage lagoon	40-60	10-30	5-25

[a]Adapted from 12, 24, 34, 45, 57, and 58.

Table 6. Nitrogen Lost at Ground Surface as Free Ammonia, by Soil Moisture/Temperature Type[a]

Days Between Application and Incorporation	Nitrogen Loss (%)		
	Warm Dry Soil	Warm Moist Soil	Cool Moist Soil
1	30	10	0
4	40	20	5
7 or more	50	30	10

[a]From Appendix Table 3 in 12.

Table 7. Collection Budget for the 80/PC/DH System

	Total Wastes (lbs)	Total Wastes (gal)	Moisture %	Total N (lbs)	Total P (lbs)	Total K (lbs)
Jan.-Feb.						
Total manure collectible[a]	542 800	65 600	87.3	2 690	480	1 795
Total manure collected[b]	434 240	52 480	87.3	2 152	384	1 436
+ Bedding and feed wastes[c]	28 320	10 592	15	120	28	85
+ Rainfall collected[d]	428 878	51 363	100			
+ Parlor wastes[e]						
- Runoff losses[f]	(366 691)	(43 915)	97.2	(400)	(77)	(718)
- Evaporation losses[g]	(15 931)	(2 130)	100			
+ Water added[h]						
Total wastes collected	50 8816	68 390	86.45	1 872	335	803
March-April						
Total manure collectible	561 200	67 830	87.3	2 782	498	1 854
Total manure collected	364 780	44 090	87.3	1 808	324	1 205
+ Bedding and feed wastes	24 400	9 126	15	103	25	73
+ Rainfall collected	408 475	48 919	100			
+ Parlor wastes						
- Runoff losses	(367 628)	(44 027)	97.7	(330)	(65)	(603)
- Evaporation losses	(61 755)	(7 396)	100			
+ Water added						
Total wastes collected	368 272	50 712	84.08	1 581	284	675

[a]Calculated from data presented in 30.
[b]Total manure collectible x %TOL.
[c]8, 7, 6, 5, and 2 lbs/day for 95, 90, 80, 65, and 45 %TOL respectively. (Adapted from 20, 23, and 24.)
[d]Total rainfall for the period that falls directly on the housing/feeding lot surface. (See Appendix Table 4.)
[e]Slurry and liquid systems only (from Appendix Table 1).
[f]80-95% total rainfall at 3.5% total solids by weight x %TOL (Adapted from 12, 24, and 35.)
[g]Evapotranspiration rate (Table A-4) x 0.7 x housing/feeding lot size x %TOL.
[h]Water added at reception pit (CAGT and SAGT systems) to raise moisture content of waste for pumping.

Table 7 (Continued)

	Total Wastes (lbs)	Total Wastes (gal)	Moisture %	Total N (lbs)	Total P (lbs)	Total K (lbs)
May-June						
Total manure collectible	561 200	67 830	87.3	2 782	498	1 854
Total manure collected	252 540	30 524	87.3	1 252	224	834
+ Bedding and feed wastes	9 760	3 650	15	41	10	29
+ Rainfall collected	326 030	390 46	100			
+ Parlor wastes						
- Runoff losses	(309 729)	(37 093)	98.4	(193)	(45)	(417)
- Evaporation losses	(104 143)	(12 472)	100			
+ Water added						
Total wastes collected	174 458	23 655	79.7	1 100	189	446
July-Aug.						
Total manure collectible	570 400	68 945	87.3	2 827	506	1 885
Total manure collected	256 680	31 025	87.3	1 272	228	848
+ Bedding and feed wastes	9 920	3 710	15	42	10	30
+ Rainfall collected	334 349	40 043	100			
+ Parlor wastes						
- Runoff losses	(317 641)	(38 041)	98.4	(198)	(46)	(424)
- Evaporation losses	(136 146)	(16 305)	100			
+ Water added						
Total wastes collected	147 172	20 432	75.57	1 116	192	454
Sept.-Oct.						
Total manure collectible	561 200	67 830	87.3	2 782	498	1 854
Total manure collected	252 540	30 524	87.3	1 252	224	834
+ Bedding and feed wastes	9 760	3 650	15	41	10	29
+ Rainfall collected	240 672	28 823	100			
+ Parlor wastes						
- Runoff losses	(228 638)	(27 382)	98.4	(143)	(45)	(417)
- Evaporation losses	(82 501)	(9 880)	100			
+ Water added						
Total wastes collected	191 833	25 735	80.86	1 150	189	446
Nov.-Dec.						
Total manure collectible	561 200	67 830	87.3	2 782	498	1 854
Total manure collected	364 780	44 090	87.3	1 808	324	1 205
+ Bedding and feed wastes	24 400	9 126	15	103	25	73
+ Rainfall collected	348 932	41 788	100			
+ Parlor wastes						
- Runoff losses	(314 039)	(37 609)	97.7	(282)	(65)	(241)
- Evaporation losses	(25 315)	(3 032)	100			
+ Water added						
Total wastes collected	398 758	54 363	84.99	1 629	284	1 037

Table 8. Storage and Application Budget for the 160/PC/EP/6 System

	Total Wastes (lbs)	Total Wastes (gal)	Moisture %	Total N[h] (lbs)	NH_4-N[h] (lbs)	Total P (lbs)	Total K (lbs)
March-April							
Total wastes collected[a]	4 218 655	539 233	91.89	10 044		1 874	6 726
- Storage nutrient loss[b]				(2 009)			
+ Rainfall on storage[c]	1 762 118	207 308	100				
+ Water added[d]							
Total wastes applied		746 531	94.29	8 035	4 018	1 640	6 053
- N loss (irrigation)[e]				(1 607)	(1 607)		
- Runoff losses[f]							
Total nutrients in-soil				6 428	2 411	1 640	6 053
Sept.-Oct.							
Total wastes collected	4 273 531	536 259	92.37	10 222		1 920	6 845
- Storage nutrient loss				(2 044)		(240)	(685)
+ Rainfall on storage	452 411	54 181	100				
+ Water added							
Total wastes applied		590 440	93.10	8 178	4 089	1 680	6 160
- N loss (irrigation)							
- Volatilization loss				(1 636)	(1 636)		
- Runoff losses							
Total nutrients in-soil				6 542	2 453	1 680	6 160

[a]Source: Collection Budgets.
[b]Sources: (34, 41, 44, and 45). The fertilizer nutrient and organic matter losses were assumed to insignificantly affect the volume, weight, and moisture content of the wastes applied.
[c]Net rainfall on open (roofless) storage facilities.
[d]Water required to facilitate pumping or treatment of wastes in slurry or lagoon systems.
[e]N loss accruing to the irrigation process (movement of wastes through the air). Source: 41.
[f]N lost at ground surface as free ammonia after application and before incorporation (v 4 days). Source: Table 3 in 12.
[g]Nutrient loss due to runoff after field application. (Adapted from 42, 39, and 40).
[h]Ammonial N plus organic N that must be mineralized before crop uptake.
[i]Ammonical N, the N that is potentially 100 percent available to crops following land application.

Table 9. Nutrient Mineralization and Valuation Budget for the 80/–PC/EP/6 System[a]

Nitrogen Year	NH_4-N	Mineralized N[b]	Total N Available in Yr. X	Total Value of N[c]	Discount Factor[d]	Present Value
1	2454 +	1 226 =	3 680	1 030 x	1.0000 =	1 030
2		613 =	613	172 x	0.9709 =	167
3		307 =	307	86 x	0.9426 =	82
4		153 =	153	43 x	0.9151 =	39
				Total annual value[e]		1 317
Phosphorus Year			Total P[f] Available in Yr. X	Total Value of P	Discount Factor	Present Value
1			1 279	895 x	1.0000 =	895
2			171	120 x	0.9709 =	117
3			82	57 x	0.9426 =	54
4			17	12 x	0.9151 =	11
				Total annual value		1 077
Potassium Year			Total K Available in Yr. X	Total Value of K	Discount Factor	Present Value
1			4 930	887 x	1.0000 =	887
2			493	89 x	0.9709 =	86
3			308	55 x	0.9426 =	52
4			62	11 x	0.9151 =	10
				Total annual value		1 035

[a]Determination of annual value of fertilizer nutrients in dairy wastes applied. Based upon data from Storage and Application Budgets.
[b]Source of mineralization rates for N: 65.
[c]Prices for elemental nutrients were derived from commercial fertilizer prices. N, P, and K were priced at $0.28, $0.70, and $0.18/lb. respectively.
[d]Discount factors were based upon a long-term real interest rate of 3 percent.
[e]Based upon the assumption that annual applications of dairy wastes are relatively constant, i.e., valuation of an average year's application.
[f]Sources of mineralization rates for P and K: 24 and 44.

Table 10. Annual Labor and Energy Cost Budget for the 80/TC/TSL/FC System

	Labor (hours)	**Labor (cost)**	**Tractor/ Equipment (hours)**	**Fuel/Lubrication (cost)**	**Electricity (kwh)**	**Electricity (cost)**
Jan.-Feb.						
Daily clean[a]	10.0					
Recycle pump[b]			383.5		268.5	13.5
Irrigation[c]						
Total	10.0	50.0	383.5		268.5	13.5
March-April						
Daily clean	10.0					
Recycle pump			396.5		277.5	14.0
Irrigation	8.5		72.5	255.5		
Total	18.5	92.5	469.0	255.5	277.5	14.0

[a]Labor required to flush (manual flush tanks) housing/feeding lots daily (2x/day if %TOL < 45, lx/day otherwise).
[b]Energy required to power a 1/2 HP recycle pump associated with the system's flush collection system.
[c]Labor and energy required to irrigate collected wastes onto cropland.
[d]Annualized cost of sludge removal assumed to be required in years 5, 10, 15, and 20 of the system's life.

Table 10. (Continued)

	Labor (hours)	Labor (cost)	Tractor/ Equipment (hours)	Fuel/Lubrication (cost)	Electricity (kwh)	Electricity (cost)
May-June						
Daily clean	10.0					
Recycle pump			396.5		277.5	14.0
Irrigation						
Total	10.0	50.0	396.5		277.5	14.0
July-Aug.						
Daily clean	10.5					
Recycle pump			403.0		282.0	14.0
Irrigation						
Total	10.5	52.5	403.0		282.0	14.0
Sept.-Oct.						
Daily clean	10.0					
Recycle pump			396.5		277.5	14.0
Water Added					127.5	6.5
Irrigation	8.5		72.0	253.5		
Total	18.5	92.5	468.5	253.5	405.0	20.5
Nov.-Dec.						
Daily clean	10.0					
Recycle pump			396.5		277.5	14.0
Irrigation						
Total	10.0	50.0	396.5		277.5	14.0
Yearly Totals	77.5	388	2 517.0	509.0	17 880	90.0
					Equipment rental	
Sludge removal (annualized cost)[d]	26		66	92		
Total Annual Cost		414		575	92	90

[a]Labor required to flush (manual flush tanks) housing/feeding lots daily (2x/day if %TOL > 45, lx/day otherwise).
[b]Energy required to power a 1/2 HP recycle pump associated with the system's flush collection system.
[c]Labor and energy required to irrigate collected wastes onto cropland.
[d]Annualized cost of sludge removal assumed to be required in years 5, 10, 15, and 20 of the system's life.

Table 11. Capital Recovery/Insurance/Repairs/Housing Costs Budget for the 160/TC/DH System

	Inital Cost[a]	Insurance/Repairs /Housing Costs[b]	Life (yrs)	% of Time to Waste-handling[c]	Capital Recovery[d]
Scraper tractor (37 HP)	16 000	166	8	55.5	1 847
Tractor for hauling (105 HP)	38 200	211	10	31.0	2 209
Box scrape (6 ft)	700	22	10	100.0	131
Box spreader (275 bu)	7 200	239	5	100.0	1 988
Concrete, curbing, etc.	1 590	16	20	100.0	213
Totals		654			6 388

[a]For reference only. Some items of equipment used for waste handling are not included in the initial cost of the system. That is, waste management is not the primary source of their annual use. See Initial Investment Budgets.
[b]Sources: 45 and 53.
[c]Based upon potential annual use; e.g., tractors have a potential annual use of 800 hours.
[d]A substitute calculation for depreciation and interest on capital.

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