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COST-SIZE RELATIONSHIPS FOR LARGE-SCALE DAIRIES WITH EMPHASIS ON WASTE MANAGEMENT

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SUMMARY AND HIGHLIGHTS

Overview

The concentration of large-scale dairy operations in the Chino Basin, located about 40 miles east of Los Angeles, poses inter-related environmental, regulatory, and economic problems. The Santa Ana Regional Water Quality Control Board brought dairies under control in 1972 in response to serious water quality problems caused by waste management. The Phase I and II regulations, which control runoff and the application of manure to land, resulted in higher costs to the regulated dairies. Dairywomen are uncertain about the possible nature and enforcement of future regulations and lack knowledge of waste management technology capable of satisfying an environmental quality objective of zero degradation from dairy wastes. The ultimate impact of waste control regulations on the cost structure and future economic viability of Chino dairies is a source of concern and is the focus of this study.

Analysis of efficient large-scale dairy production in the context of environmental quality objectives involves consideration of the role of waste management in the production of milk and the underlying cost structure. To this end, short- and long-run costs for large-scale dairying, including waste management, were estimated. The economic-engineering approach was utilized for the analysis. The dairy was disaggregated into five stages: milking, housing, feeding, waste management, and management and record keeping. Within the first three stages, costs were synthesized from detailed analysis of elemental production specifications and restrictions. Particular emphasis was placed on new semi-automated milking techniques and

alternative feeding programs. Cost estimates for the waste management stage were synthesized largely from published sources. Necessary design parameter modifications, however, were made to assure process compatibility with dairy wastes. On-dairy costs in the form of commercial collection services, additional labor, and dairy facility modifications were estimated for each treatment and disposal method.

The dairies considered in this study were organized as specialized single enterprise units producing only fluid milk. Alternative combinations of milking parlor and housing configurations, feeding programs and rations, and equipment and labor complements yielded over 200 different complete dairies. From these, 14 single parlor dairies with capacities ranging from 375 to 1,200 cows were modeled. Short-run average costs were estimated for each of these model dairies. A combination of these single parlor dairies into multiple parlor configurations yielded 15 dairies in the 1,200 to 3,600 cow herd range for a total of 29 model dairies.

Waste disposal methods selected for analysis included three large-scale treatment methods with material or energy recovery capabilities, one municipal disposal method, and current disposal practices. Energy and material recovery capabilities were found to be advantageous for large-scale treatment methods. We demonstrate that separate analysis of dairy and waste disposal costs can lead to a sub-optimal decision since the waste disposal method utilized must be compatible with dairy housing.

The long-run average cost curve (LRAC) was derived as an envelope to the short-run average cost curves. Both semi-automated milking systems and group feeding programs offer potential

efficiencies to large-scale dairies. The dry lot/incineration system was the least-cost waste disposal alternative considered. The estimated LRAC curve reveals significant economies of size in the 375-750 cow range and only slight cost reductions for dairies in excess of 1,200 cows. Annual unit costs, for example, decrease from \$1,065 for 375 cows to \$1,001 for 750 cows to about \$994 for 3,600 cows.

Conclusions and Implications

Dairymen in the Chino Basin are confronted with the difficult task of managing wastes in compliance with stringent environmental quality controls. Under the present industry structure, these controls place considerable stress on the competitive situation of the Chino dairies. However, it is not clear--as some suggest--that dairies will be forced out of business or will relocate out of the Chino Basin. Based on the analysis presented in this study, enforcement of environmental quality controls need not raise the costs of dairy production in the long run. The recent development of improved dairy production techniques, coupled with scale economies available from regional waste treatment and disposal methods, potentially allow for a substantive change in the Chino dairy industry cost structure. The cost of milk production theoretically could decline from present levels and still comply with environmental quality controls. This will require investment in automatic milking parlor equipment and some increase in the average size of dairy.

Care must be taken not to misinterpret the above conclusions. The LRAC curve derived in this study is an estimate of the level of costs that are theoretically possible, and neither explains nor

implies any particular investment path toward this theoretical efficiency frontier. There is no certainty that costs will decline to the LRAC curve. The potential cost savings, however, suggest incentives exist for adjustments leading to a decline in cost and an increase in average herd size. Conditional upon the ceteris paribus assumption that milk price and input price relations remain relatively unchanged, the adjustments would enhance and perhaps preserve a viable dairy industry in the Chino Basin. Milk production levels could be maintained for some time into the future. A dramatic change in the industry structure, however, would be necessary to support this conclusion. Credit availability and managerial capabilities would probably prevent many of the existing dairies, particularly smaller ones, from making the required adjustments. The displaced resources, however, could be consolidated into larger production units resulting in fewer but larger firms.

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COST-SIZE RELATIONSHIPS FOR LARGE-SCALE DAIRIES
WITH EMPHASIS ON WASTE MANAGEMENT

by

Scott C. Matulich, Hoy F. Carman, and Harold O. Carter*

INTRODUCTION

Livestock production in much of the United States has been shifting from small-scale diversified units to large-scale confinement operations feeding high concentrate rations. This attempt to realize increased production efficiency has resulted in waste management problems. Large concentrations of livestock waste pose disposal problems and may result in health hazards and environmental degradation. The waste disposal problem is complicated by: (1) increasing pressure from urban growth (in terms of both land availability for disposal and attitudes towards the rural environment), (2) the widespread substitution of chemical fertilizers for manure as a soil conditioner and plant nutrient source, and (3) the increasing cost of farm labor in what traditionally has been a labor intensive operation (Hart and Turner, 1965; Loehr, 1968; Witzel et al., 1969; and Good, 1973).

Livestock waste management practices have recently fallen under scrutiny by governmental environmental resource agencies. Due in part to changing technology and structure of the industry, legal regulations currently facing the livestock industry are becoming

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more stringent. Johnson et al. (1972) provide a summary of air and water quality statutes applicable to livestock waste management. Development and adoption of waste management methods and means not widely utilized in agriculture may be required to comply with these discharge regulations.

The emphasis on pollution control has increased research in the area of animal waste management. Since 1965 the animal waste management literature has focused on expanding technical knowledge of waste treatment and disposal methods. Most of this literature demonstrates technical feasibility and process design criteria. However, this preoccupation with technical effectiveness has promoted a general misconception that waste management is commonly regarded as an engineering feat--a treatment and/or disposal process that is "added-on" to the production system to satisfy environmental quality regulations. That is, waste management is relegated to the status of "something to take care of" after efficient production is ensured. It is generally believed that costs of waste management are thereby minimized by minimizing treatment and/or disposal costs. This study demonstrates that waste management is an integral component of the overall production-marketing system and must be analyzed accordingly.

The Problem

The trend away from the traditional farming operation and towards a more specialized factory-type operation is exemplified by dairying in the Chino Valley of California, located about 40 miles east of Los Angeles in the southwestern portion of San Bernardino County and the northwestern corner of Riverside County.

Dairymen in this area are confronted with a unique situation that compounds the normally difficult task of manure disposal. The Chino Valley with over 20 percent of California's dairy herd, has the world's largest concentration of dairy cows. While the area totals about 50 square miles, irrigated pasture and cropland suitable for manure disposal totals only 12,500 acres. Approximately 167,000 cows are contained within this small area--more than 13 cows per disposal acre. Over 9,000 tons of manure and about 8 million gallons of waste water are produced daily. Herds of 400 to 600 cows are confined to 10 to 60 acres; several herds are in excess of 2,000 cows.

The large volume of dairy wastes has caused a serious problem of both solid and liquid wastes disposal. Past waste management practices have been to collect periodically and haul untreated, dry manure from the dry lot loafing pens to fields where it is spread. Barn wash and other liquid wastes are used to irrigate nearby fields. Heavy rains in December and March have caused serious runoff problems resulting in the organic loading of nearby streams, stormdrains, and ultimately the Santa Ana River.

Past and present methods of managing dairy wastes in the Chino Basin have allegedly caused the deterioration of surface and ground water. The beneficial use of Basin waters has been limited by: (1) excessive nitrate concentrations in domestic water supplies, (2) adverse salt balances and excessive mineralization of ground water, (3) public health hazards from viral and bacterial contamination of recreational surface water, and (4) large algae blooms and fish kills. In response to these problems, the Santa Ana Regional Water Quality Control Board adopted a dairy waste control policy in 1972.

A basin-wide environmental quality objective of zero degradation from dairy wastes was adopted and a two phased regulatory program specifying discharge requirements for each dairy was enacted.^{1/}

Control of runoff and application of manure to land was the major focus of the discharge requirements. Phase I requires each discharger to provide facilities (lagoons) to contain runoff from manured areas that would result from 1.3 times the 10 year maximum 24 hour rainfall at that location. Phase II limits annual manure application per acre to 1.5 times the amount of manure produced by one cow in one year.

Traditional dairy waste management methods in the Chino Basin are inadequate to achieve the environmental quality objectives. Restriction of spreading manure on Basin Land forces the dairymen who wish to continue operating at the same level of output in the Basin to adopt improved waste management practices. This can place considerable economic stress on the ability of the Chino dairy industry to compete with other regions (primarily the Southern San Joaquin Valley) in supplying the Los Angeles market. Many dairymen argue that compliance under the current industry cost structure could be sufficient to force dairies out of business or to relocate.

The economic importance of the dairy industry to the Chino Basin is great. The combined sales from dairies in San Bernardino and Riverside Counties, of milk to processors and dairy cows and calves to the meat industry, totaled over \$160 million in 1972. Capital investments of dairies in excess of \$230 million contribute

^{1/} For an expanded discussion of present and potential dairy waste discharge requirements, see Matulich (1976, pp. 158-162).

more than \$6.5 million in tax receipts to local governments (A. A. Webb Associates, 1974). In addition to these direct effects, the dairy industry indirectly generates a variety of other goods and supporting services through a multiplier effect. Indeed, most agree that presence of a viable dairy industry has far reaching economic consequences to the local economy.

Assessment of the impact of waste control regulations requires detailed cost data for both dairying and waste management. A review of the literature revealed a lack of current studies for large-scale specialized dairies such as found in the study area.^{1/} Thus, a detailed study of costs of dairying and waste disposal was necessary.

Study Objectives

The overall objective of this investigation is to examine the potential cost structures of dairying in Chino, emphasizing a total systems approach, consistent with basin-wide environmental quality objectives and controls. The specific objectives of this study are:

- (1) To specify and evaluate alternative dairy waste management technologies, including large-scale regional methods, that can satisfy environmental quality objectives in the Chino Basin.
- (2) To identify alternative dairy production technologies from a detailed analysis of elemental production specifications and restrictions.
- (3) To develop cost-volume relationships for large-scale, specialized milk production enterprises, including waste management.

^{1/} For a review of the literature on costs of dairying and waste disposal, see Matulich (1976, pp. 35-41).

- (4) To evaluate the impact on the dairy production system of managing wastes in compliance with the environmental quality objectives.
- (5) To ascertain the analytical importance of integrating waste management with the dairy production system, i.e., to evaluate the importance of a systems approach to waste management.

Cost synthesis provides the basic approach to achieving these objectives. Insights into the potential economic viability of the Chino dairy industry should be gained from the analysis presented in this study. Existence of potential economies of size should suggest the direction and magnitude of potential future structural change for the firm and industry.

METHODOLOGY AND ANALYTICAL FRAMEWORK

Economies of Scale

The analysis of economic efficiency involves both short- and long-run considerations where the length of run is determined by the range of variability of factors of production. In the long-run all factors are variable while in the short-run one or more factors are fixed. This distinction is important in the derivation of the relevant cost relationships.

The concept of economies of scale is typically illustrated with reference to the shape of the long-run average cost curve (LRAC) for a single product firm. The long-run average cost curve (LRAC) is an envelope to a series of short-run average cost curve (SRAC) as illustrated in Figure 1. The short-run curves show the minimum cost of producing various levels of output with one or more factors of production fixed. The fixed factor may be a piece of machinery, floor space, or some other determinant of plant size. In the case

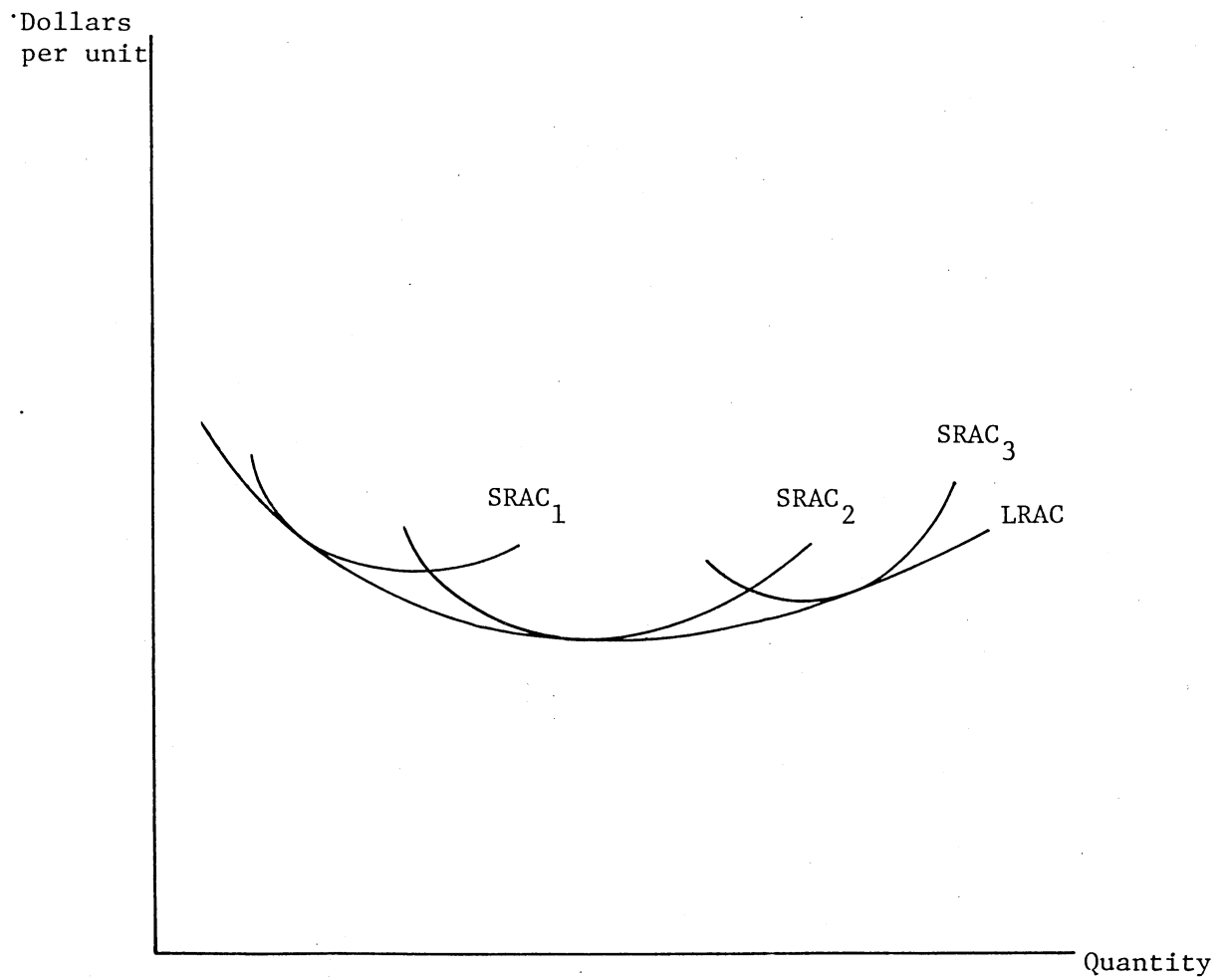


Figure 1. Illustration of Theoretical Short- and Long-Run Average Cost Curves.

of large-scale dairies, size can be measured by the capacity of the milking parlor. The short-run is long enough to permit variation in labor, cows, feed, and other productive inputs but not to vary the capacity of the milking parlor.

Short-run average cost curves (SRAC) are usually considered to be U-shaped as illustrated in Figure 1. Given a fixed plant, costs first decrease as fixed costs are spread over more output and then increase as a result of decreasing marginal physical product as more variable factors are employed in the fixed plant. This is illustrated in a dairy by the addition of cows and labor in a fixed milking parlor.

The theoretical LRAC curve, formed as an envelope tangent to the family of SRAC curves, is also U-shaped. Economies of size are said to exist over the range of outputs where average unit costs of production decline as firm size increases. Diseconomies of size are said to exist throughout the range of outputs where average unit costs of production increase as firm size increases.

The theoretical decline and eventual increase in LRAC are usually explained by technical and managerial forces. Technical forces responsible for declining unit costs are largely a result of factor specialization, combined with indivisibilities or lumpiness in certain factors. While factor specialization is an effective means of promoting greater productivity, indivisibilities often preclude capturing economies from specialization. Many factors of production are available only in finite, discrete capacities which small firms are unable to fully utilize. Even when specialized factors are available in a variety of sizes, the cost per unit of capacity is often greater for the small factor as

compared with its larger counterparts. Thus, a broader range of technologies are available to larger firms, offering them greater combinations of inputs and affording better use of a particular input combination. Specialized administrative and managerial skills also may be better utilized by larger firms. Not only are unit costs of management typically lower for larger firms, but firm size may increase without a proportional increase in management.

The theoretical region of increasing long-run average costs is the focus of controversy. Few studies have found empirical evidence of diseconomies of scale (French, 1977). While managerial factors are cited as contributing to economies of scale, most of the theoretical discussions regarding diseconomies argue that management, or lack thereof, is the main factor causing an eventual upturn in the LRAC curve. Beyond some size, effective managerial ability is strained, and management becomes incapable of coordinating all production-marketing activities.

The conventional treatise on estimating cost functions involves only internal economies of size. External economies are usually taken as given, and only implicitly considered in that the present industry development may or may not reflect external economies. For example, a highly concentrated industry supports a host of productive services unavailable to a more diffused industry. Explicit separation of internal and external economies of scale, however, is especially useful for this study. The magnitude of pollution is primarily attributable to the concentration of dairies in the Chino Basin, and is therefore, an external diseconomy. Alternatively, the industry concentration may afford external economies of scale

in regional waste management not available to the individual dairy. Hence, both internal economies in large-scale dairying and external economies in regional waste treatment and disposal are explored.

Considerations in Estimating Cost-Volume Relationships in Dairy Production

Conventional neoclassical economic theory has limited applicability for analysis of costs and efficiency for many agricultural firms. French, Sammet, and Bressler (1956) recognized these limitations and reformulated the conventional theoretical constructs into a suitable framework for empirical analysis. They observed that most plant operations are characterized as an integration and aggregation of various production processes or stages. The goal of efficient production, then, is to coordinate all production stages into an harmonious whole, yielding a particular level of output at minimum cost. Empirical determination of optimum input-output combinations must be based on a detailed examination of elemental production relations. Major considerations in an empirical analysis of firm efficiency include: 1) the degree of factor substitution and intensification, 2) plant segmentation and the discontinuous nature of cost functions, and 3) distinction between the rate and time dimensions of short-run cost variations.

Variations in the Rate of Dairy Production

The most commonly recognized method of altering the rate of production is by changing the number of workers employed in particular production activities. In dairying, intensification of labor usage resulting in a change in output is limited. The number of milkers employed could conceivably be varied, changing the amount

of idle time during the milking operation. For any particular milking parlor-equipment set the most efficient labor complement is predetermined. Intensification of milker labor beyond this level produces a crowding effect which yields marginally greater output only at significantly higher costs. The alternate source of variation in labor is the substitution of a cow chaser for that portion of the milker's activity. This substitution promotes specialization of the higher priced milker labor, yielding potentially greater output at lower costs than otherwise possible.

An alternative potential source of variation in the rate of dairy production is the feeding level. The potential for short-run adjustments in cost-volume relationships resulting from changes in feed intake is well documented. Agricultural economists have long recognized that the feed-milk production response does not reflect a constant rate of substitution among feeds, nor a constant return to feeds. Variations in the rate of production due to feeding are commonly handled by examining the substitutibility between the roughage-concentrate components of the ration.^{1/}

Variations in Time of Dairy Production

Potential variations in the time dimension for dairying are twofold. The number of hours spent in the production process is variable, and there exists the opportunity for operating double shifts.

Number of Hours per Shift. The milker union wage agreements are based on the daily average number of cows milked per month and

^{1/} A number of studies are available. For an example of the approach, see Heady et al. (1956).

the particular milking parlor configuration. With fringe benefits excluded, milker's salaries can be characterized as a piece rate arrangement. Thus, the total milker wage bill for a particular parlor will vary directly with the number of hours worked. The present milker wage schedule is structured with a step decrease in price rates for more than 300 cows. This is to encourage employers to maintain a larger milking herd.

Short-run expansion in the time/cow dimension is ultimately limited by the milking parlor capacity. The maximum dairy size (for a single milking parlor dairy configuration) is technically determined by the particular parlor configuration and maximum time milking per shift. Expansion beyond this level requires a long-run adjustment via construction of additional facilities including another milking parlor. However, when the parlor capacity is not fully utilized, housing becomes the bottleneck to short-run expansion. Expansion beyond housing capacity requires construction of additional housing facilities.^{1/} Conversely, short-run contractions in herd size are conceptually unlimited.

Double Shifts. Double shift milking operations offer a logical approach to expand dairy production. Idle excess capacity of the milking facilities may be utilized more fully, thereby reducing

^{1/} The definition of housing capacity is critical in determining the extent of short-run expansion. The distinction between design capacity and physical capacity is important for this determination. Design capacity refers to the optimum number of cows per housing unit, whereas, physical capacity refers to the maximum number of cows per housing unit. Although expansion beyond design capacity is often possible, crowding results in diminished productivity per cow, and therefore, increased average costs. Because the detrimental effect of crowding is unmeasured, we use housing capacity to denote design capacity.

unit costs of production. In fact, much of the fixed costs throughout the entire dairy may be spread over twice the production base. Unlike many production operations, there is little institutional resistance to double shifts. In the study area there is no wage differential between shifts. The recent trend towards double shift dairy operations in the Chino region is largely explained by this lack of resistance and unit cost reduction. It should be recognized, however, that a change from one to two equivalent shifts does not constitute a short-run expansion in dairy production. Housing capacity must be duplicated. No attempt is made to compare costs of single versus double shifts in this study. Only double shift dairy operations are analyzed.

Discontinuities in Dairying

Most empirical cost studies specify relatively few plant sizes and fit a smooth continuous envelope to the estimated plant SRAC curves. This method avoids enumeration of all possible production techniques and associated discontinuities. However, theoretical representation of the LRAC curve as a smooth, continuous envelope assumes an infinite number of plants and, therefore, an infinite opportunity to vary input-output combinations. Reasonable continuity may be approached if there exists a large number of production techniques and production operations (French, 1977). Neither of these conditions are satisfied with respect to large-scale dairying. Consequently, an empirically meaningful LRAC curve that is useful as a planning device, must explicitly recognize potential discontinuities. Representation of the LRAC curve for dairying as a

smooth, continuous frontier would show erroneous or unattainable cost-volume relations, particularly for some of the smaller size dairies.

Research Approach

The economic-engineering approach forms the methodological basis for this study. French (1977) describes the economic-engineering approach as a sequence of four procedural steps: (1) examination of system structure through complete specification of the nature and sequence of plant operations; (2) specification of alternative production techniques for each stage; (3) formation of stage production functions from tabulation of all input-output relationships, and formation of total plant production functions by summing over various stages; and (4) development of short-run cost functions by applying constant factor prices to the production functions, and combining the short-run cost functions for various output ranges to obtain the long-run cost function.

Our derivation of cost relationships as outlined by French (1977) is straightforward. The dairy was divided into the various stages; detailed input-output relationships were specified for each stage and these were combined into model dairies of various sizes. The required quantities of fixed and variable inputs combined with their market prices yielded the short-run cost function for each model dairy. The long-run cost curve was then fitted as an envelope to the synthesized short-run cost curves.

COST RELATIONSHIPS FOR THE DAIRY PRODUCTION SYSTEM

Technological options are examined in this section on a stage-by-stage basis; single parlor dairies ranging in size from 375 to 1,200 cows are modeled. Physical input-output relations are specified for each stage and cost estimates are synthesized.^{1/}

Stages of Dairying

For analytical purposes of this study, the cost components of dairying are defined as consisting of four operating stages and a general cost component. A brief description of these stages provides an overview of the activities taking place in the dairies studied. Following is a description of the stages and their associated activities.

1. Milking: Milking consists of the interdependent jobs of cow collection and wash-up, milking, and clean-up and milk storage. Cow collection and wash-up involves gathering, holding, and washing cows prior to milking. Physical plant investment includes the holding facilities and cow washing equipment. Variable costs include utilities and labor to chase cows. The milking job includes set-up of equipment and milking. Numerous alternative technologies are available and the investment in durable physical plant (milking parlor, milking equipment, pipelines, compressors, etc.) is large. Variable costs include milker labor and utilities. Costs incurred

^{1/} In general, cost estimates for the dairy production system were synthesized from detailed elemental component specifications and restrictions. These estimates are presented in Appendix Tables A-1 through A-10. An illustration of the particular facility precedes the corresponding tables.

in both cleanup and milk storage are closely related to the milking operation. The milk house, cooling system equipment, and sanitation equipment are the primary fixed costs. Much of the equipment is common to the milking job, e.g., pipelines and pumps connecting the milking parlor to the cooling and storage system. Variable costs include labor for disassembly, cleaning and sanitation of milking equipment and facilities, and utilities and cleaning supplies.^{1/}

2. Housing: Housing investment is largely contingent upon climatic conditions. The relatively mild winters and hot summers in the study area limit the number of alternatives. Housing design is closely related to the milking parlor design and size, feeding system, and waste handling. Facilities for breeding, care of calves through the first week, and hospital pens must be included.

3. Feeding: This stage involves purchase, storage, and delivery of feed to the cows. Each component of this stage is dependent, to some degree, upon the specific feed program and, therefore, the form in which feed is purchased and fed. A variety of storage facility options are available. Equipment to transfer feed from storage to the cows depends upon the type of storage facilities, degree of automation, and the feeding program. Feed delivery equipment may be stage specific or general to the dairy operation, e.g., a feed wagon and a front end loader. The principal variable costs are feed and labor.

^{1/} Because of job organization for the model dairies in this study, cleanup is performed by miscellaneous labor included in the management stage.

4. Waste Management: Feed, drinking water, and wash water are transformed during the feeding, milking, and housing stages into waste products. Each of the production stages, in conjunction with weather, determine the ultimate quantity and composition of waste requiring treatment and/or disposal. But not all of these elements are equally effective focal points for controlling the waste generation. Technical limitations eliminate the feeding stage as a control instrument. Water utilization is responsive to managerial control and should be minimized. However, the specific milking technology (more specifically, the type of washing operation) and strict state guidelines effectively eliminate the milking operation as a source of control. Weather is exogenous and not directly controllable. Housing, however, is an important consideration in waste management. Housing can effectively control weather induced waste flows (runoff) and also augment the collection function of waste management.

The waste management system includes collection, transportation, treatment, and disposal. The development of cost estimates varies by function. For collection the rates charged by contractors are used. Transportation costs are estimated for hauling in trucks and for a gravity flow liquid conveyor system. Costs for treatment and disposal consider four alternatives. For each alternative, cost estimates include annual fixed costs associated with facilities plus annual operating and maintenance costs. Three of the treatment processes yield energy which helps to reduce their net costs.

5. General Dairy Costs: This stage ties together all of the other stages of production to make the dairy operative. Costs of durables and some variable costs are directly measurable, e.g.,

office facilities and accountant and legal services. However, specific managerial labor requirements and costs are extremely difficult to estimate. Costs not assigned to the other stages are included in this stage. Major categories include land costs, cow costs, breeding, medicine, veterinary services, calf care, taxes, insurance, and miscellaneous variable costs.

Study Specifications

Definition of Herd Size

Throughout this study a distinction is made between lactating and dry cows. This distinction is essential because much of the dairy costs accrue to the lactating cows only. For the purpose of this study, total herd size equals milking plus dry cows, where the relative proportions are 80 percent and 20 percent respectively. Costs applying only to lactating cows are reported on a "milking cow" basis, whereas costs applying to the both lactating and dry cows are reported according to "herd size."

Definition of Dairy Output

Output is defined exclusively as 3.5 percent fat corrected milk. Since available milking parlor performance data is indexed to a specific production level, milk production per cow is assumed fixed at 15,000 pounds per year.^{1/} Hence, capacity can be measured as the number of cows, which in turn defines a specific quantity of milk.

^{1/} Production of 15,000 pounds of milk per cow per year was representative of well-managed dairies in the Chino Basin at the time of the study.

Short-Run Variation in Feeding

Variation in the quantity and composition of feed was identified earlier as an important variant in the rate dimension. In the context of this study, however, feeding cannot alter the rate of production. Fixing milk production at 15,000 pounds per cow precludes analysis of the feed-milk production response. Instead, cost relations are examined for three alternative feeding programs, and the optimum feeding program is determined for the various herd sizes.

Definition of a Shift

A shift is defined by the number of hours per day spent in the milking operation. Union contracts in the Chino area require a milking shift be no less than six hours nor more than ten hours.

Depreciation

Depreciation of durable factors can be theoretically divided into depreciation from usage, time, and obsolescence. Empirical separation of depreciation into its three components, however, is not possible with available data. The straight line method is employed in this study. Expected use life of durable factors are chosen to reflect the various depreciation components.^{1/} The estimated use life of all buildings and feed storage facilities is 20 years. Dairy equipment have various use lives specified in the

^{1/} Data from the California Bureau of Milk Stabilization form the basis for the selected use-life estimates employed in this study. Some adjustments to reflect special considerations were required.

following tables. Depreciation is computed on the difference between total construction or purchase cost (including any freight charges, sales tax, and installation charges) and estimated salvage value. Salvage value is assumed to be 10 percent of initial cost.^{1/}

Interest Costs

Cost of capital in the form of interest foregone on money invested in durable factors, is a major cost to the dairy. Two interest rates are used in this study. An interest rate of 9 percent is used to reflect private money market conditions for June-July 1975. Alternatively, a 7 percent interest rate was used in computing capital costs for off-dairy waste treatment and disposal projects that are assumed to be publicly funded through the establishment of a special tax-free waste district.

Costs of depreciation and interest on investment are combined in this study into a single factor--a capital recovery factor (CRF). A CRF reduces the total cost of capital to a fixed annual amount, given the interest rate and use life of the asset. In this sense, a capital recovery factor treats the cost of depreciation as an annuity, and therefore, is merely a method of straight line depreciation which includes the average annual cost of compounded interest.

^{1/} Salvage value for individual items will vary for a number of reasons. The California Bureau of Milk Stabilization suggested that 10 percent of initial cost is a reasonable estimate of average salvage value.

The Milking Stage

The milking operation is the core of the dairy system. While efficient dairying is attributable to a variety of factors, such as nutrition, breeding, genetic quality, herd health, and general managerial ability, a good milking procedure is critical. The milking operation culminates all other production activities, determining whether or not expected production levels are realized.

Alternative parlor types and varying degrees of mechanization are of primary importance in determining the annual cost of the milking stage. Although there are six basic types of milking barns or parlors, this report is concerned with large-scale dairies and only side-opening, herringbone, and polygon parlors are considered.^{1/} Each of the three milking systems considered may be mechanized to varying degrees. Mechanical aids to promote cow movement (both in and out of the barn), udder washing, stimulation, and milking machine detachment are available.

Performance and Cost Standards

Mechanization options and parlor alternatives combine to establish the basic performance standards of the milking operation. Until recently, reported parlor performance characteristics have not included estimates applicable to large parlors common in

^{1/} Floor plans for the side-opening, herringbone, and polygon milking parlors are included as Appendix Figures A-1, A-2, and A-3. The other three milking barns or parlors are the stanchion barn, the walk-through parlor, and the rotary parlor. The stanchion barn and walk-through parlor are omitted because they have little merit in a large-scale dairying environment. While the rotary parlor is the most mechanized, wide variation in design and general lack of data preclude it from consideration.

the Chino area. A four year cooperative research program between Michigan State University and the University of Arizona, compared milking system performance under alternative mechanization options (Bickert, Gerrish, and Hutt, 1972; Bickert, Speicher, and Armstrong, 1973; Armstrong, Speicher, and Bickert, 1973; Bickert, Gerrish, and Armstrong (undated)). Parlor performance standards were initially simulated. Later, as some of the mechanized parlors came into operation, the simulated estimates were replaced with time measurement studies conducted during actual operation of parlors. Performance standards developed in these studies are utilized here.

Performance Standards. The performance standards for specific parlor/mechanization combinations considered in this study are presented in Table 1.^{1/} Only complementary degrees of mechanization are considered. In all cases, crowd gates are utilized to promote cow movement. Cow washing is accomplished with a jet washing system, except when wash stalls are used in conjunction with side-opening parlors. Manual gate operation combines with swinging machines, conventional powergates combine with stationary machines, and automatic gate operation combines with auto detachers. In-place equipment cleaning is assumed for all milking systems except swinging units. In no case is feed provided in the parlor. Stimulation of milk let down is done manually except in side-opening parlors that use stimulation stalls.

^{1/} Performance is measured as throughput in cows/hour, based on 15,000 pound annual production per cow. Throughputs presented in Table 1, however, do not account for idle time. As milker workload increases, idle time decreases. While the decline in idle time is desirable to a point, too little results in operator stress and a subsequent decline in productivity. Idle time is positive in all cases except for the 32 polygon.

The throughput figures presented in Table 1 combine with the basic housing unit sizes and number of hours per shift in determining the capacity of alternative parlor configurations. There are two equivalent milking shifts each day and all milking strings must be milked during each shift.^{1/} Thus, parlor capacity is defined by the number of complete strings that can be milked within the time constraint of 10 hours.

The herd sizes and milking times corresponding to the various parlor configurations and basic housing unit sizes of 80, 100, and 120 cows, are presented in Tables 2(a) and (b). The milking times presented in Table 2(a) are based on the assumption that milkers spend 20 minutes per string chasing cows.^{2/} The maximum number of cows milked in a single parlor under this arrangement is 720. In Table 2(b), the assumption that milkers chase cows is relaxed and two 15 minutes rest periods are explicitly included in the milking times. Lower priced cow chasers substitute for the corresponding milker labor.^{3/} By relieving the milker(s) from cow chasing, milking

^{1/} A milking string is that portion of a cow herd in a single corral or housing unit.

^{2/} Total time spent chasing cows is a function of the number of milking strings and ranges from one hour to more than three hours.

^{3/} The substitution is not a 1:1 transformation. Residual cow chaser capacity must also supplement general outside labor. Two factors may offset cost reductions over certain herd sizes. First, particular size dairy operations may not be able to utilize the supplementary outside labor capacity provided by the chaser. Secondly, dairies with two milking shifts do not operate a second outside shift. Consequently, supplementary labor capacity of a cow chaser may go unused throughout the second shift. Substitution of a cow chaser for milker labor expended in cow chasing is analyzed later in this chapter.

Table 1. Milking Parlor Performance Standards, by Parlor Configuration.

Milking parlor configuration				Labor standards	
Parlor classification	Type of milking machine	Number of milking units	Cows per hour	Number of men milking	Cows per man hour
<u>Herringbone</u>					
Double 5	Swinging	5	45	1	45.0
	Conventional	10	50 ^{a/}	1	50.0 ^{a/}
Double 8	Swinging	8	74	2	37.0
	Conventional	16	79	2	39.5
	Auto	16	75	1	75.0
Double 10	Conventional	20	98	2	49.0
	Auto	20	86	1	86.0
Double 12 ^{b/}	Auto	24	91	1	91.0
Double 16 ^{b/}	Auto	32	103	1	103.0
<u>Polygon</u>					
4x6	Auto	24	112	1	112.0
4x8	Auto	32	116	1	116.0
<u>Side Opening</u>					
Double 3	Auto	6	68	1	68.0
Double 4	Auto	8	74	1	74.0

a/ Extrapolated.

b/ Double 12 and 16 auto figures were simulated. When compared to recent field observations they appear high. Therefore, they are assumed valid only when used in conjunction with split parlor for rapid exit.

Source: The performance standards are obtained from Bickert, Speicher, and Armstrong (1973); Bickert, Gerrish, and Hutt (1972); and Hoglund, Speicher, and Boyd (1967).

Table 2. Milking Time Per Shift With and Without Hired Chasers, by Milking Herd Size, Housing and Parlor Configurations.^{a/} ^{b/}

Without Hired Chasers ^{c/}															
Milking cows	Housing size	Housing units	Herringbone								Polygon		Side-Opening		
			Double										Double		
			5		8			10		12	16	24	32	3	4
			Swing	Conv.	Swing	Conv.	Auto	Conv.	Auto	Auto	Auto	Auto	Auto	Auto	Auto
-----hours-----															
300	100	3	7.67	7.00											
320	80	4	8.44	7.73											
360	120	3	9.00	8.20											6.29
400	80	5		9.66	7.07	6.72	6.99								7.54
	100	4		9.33											7.21
480	80	6			8.49	8.08	8.40								9.06
	120	4			7.82	7.41	7.73								8.39
500	100	5							7.47						9.01
560	80	7			9.90	9.41	9.80								9.90
600	100	6						8.12	8.98						
	120	5			9.77	9.26	9.66	7.78	8.64	8.25	7.49				9.77
	100	7						9.47							
720	120	6						9.35		9.91	8.99	8.43	8.21		
With Hired Chasers ^{d/}															
300	100	3	7.17	6.50											
320	80	4	7.61	6.90											
360	120	3	8.50	7.70											
400	80	5	9.39	8.50											6.38
	100	4	9.39	8.50											6.38
480	80	6			6.99	6.58	6.90								7.56
	120	4			6.99	6.58	6.90								6.99
500	100	5							6.31						7.85
560	80	7			8.07	7.59	7.97								8.74
600	100	6						6.62	7.48						9.32
	120	5			8.60	8.10	8.50	6.62	7.48	7.09					9.32
640	80	8			9.15	8.60	9.03								9.91
700	100	7						7.64	8.64						9.96
720	120	6				9.61		7.85	8.87	8.41	7.49	6.93	6.71		
800	100	8						8.66	9.80						
840	120	7						9.07		9.73	8.65				
900	100	9						9.68							
960	120	8									9.82	9.07	8.78		

^{a/} Double shifts.

^{b/} Milking time does not include preparation and clean up.

^{c/} Includes time spent chasing cows at 20 minutes per round trip, which in turn includes two 15 minute rest periods during the day.

^{d/} Includes two 15 minute rest periods.

Source: Derived from Table 1.

parlor throughput--measured as cows milked per work day--is increased. Maximum single parlor milking herd size is increased from 720 to 960 cows.

Labor Costs. The milkers wage schedule is shown in Table 3. Monthly salaries based on a six day work week increases in increments of 20 cows milked once daily. On a single continuous shift basis, the marginal per cow monthly wage rate is constant at \$2.86 up to 300 cows, and then declines to \$2.285 per cow. The relief milker wage schedule is also shown in Table 3.

Combining the milkers wage schedule in Table 3 with milker labor requirements in Table 2 yields the monthly cash salaries for milkers for one shift as shown in Table 4. Cash salaries in Table 4 differ from the rates shown in Table 3 for the same number of cows because of adjustments.^{1/} The lower monthly salaries for all herd size and parlor combinations in Table 4(b) as compared with 4(a), primarily reflect the allowance for not chasing cows. As shown in the management stage where cow chaser costs are included, this differential is partially offset by compensation paid to the hired cow chaser. Tables 5(a) and (b) show the relief milker monthly wage bill per shift corresponding to Tables 4(a) and (b).

The total monthly wage bill for one shift of milkers is the total of monthly cash salary from Tables 4(a) and (b) plus monthly relief milker wage bill from Tables 5(a) and (b). This must be

^{1/} As a computational example, consider 600 cows, 120 cow housing unit, and double 8 automated herringbone parlor. The adjustments are no cleanup, 60 cows and large corral, 10 cows yielding adjusted number of cows of 530. From Table 3, the monthly wage for 530 cows is \$1,618.63. The adjustment for automation results in wages of \$1,078.98 as shown in Table 4.

Table 3. Milker's Steady Monthly and Relief Daily Wage Schedule,
by Number of Cows.^{a/}

Number of cows		Steady wage		Relief daily wage
Split shift	Continuous shift	Total monthly	Marginal	
			per cow rate	
		-----dollars-----		
120	240	920.88		37.50
130	260	978.11	2.860	40.00
140	280	1,035.32	2.860	42.00
150	300	1,092.54	2.860	44.50
160	320	1,138.31	2.285	46.00
170	340	1,184.10	2.285	48.00
180	360	1,229.87	2.285	49.50
190	380	1,275.65	2.285	51.50
200	400	1,321.42	2.285	53.00
210	420	1,367.20	2.285	55.00
220	440	1,412.98	2.285	56.50
Adjustments:				
(a) An allowance of 15 cows per 100 milked per employee may be deducted if a chaser is employed and the milker does not leave the pit to get cows from the corral.				
(b) An allowance of 10 cows per 100 milked per employee may be deducted for no clean up.				
(c) Large corrals (> 100 per corral) - no chaser - an allowance of 5 cows per 100 milked in excess of 400 per employee. No allowance first 400 milked.				
Automated systems: ^{b/}				
Automatic machine removal systems are initially negotiated at 2/3 of the regular rate. This approximately reflects the normal wage on an hourly basis, plus a differential for additional responsibility.				

^{a/} Per cow rate based on two complete separate shifts.

^{b/} Private conversation with Berne Vander Weide, Secretary-Treasurer, Dairy Employees Union, Christian Labor Association.

Source: Master Labor Agreement, Dairy Employees Union, Christian Labor Association, (April 1, 1975 through March 31, 1976).

Table 4. Steady Milker Monthly Wage Bill Per Shift: With and Without Hired Chasers, by Milking Herd Size, Housing and Parlor Configurations.^{a/,b/,c/}

Without Hired Chasers															
Milking cows Housing size Housing units			Herringbone								Polygon		Side-Opening		
			Double								24	32	Double		
			5		8		10		12	16			3	4	
			Swing	Conv.	Swing	Conv.	Auto	Conv.	Auto	Auto	Auto	Auto	Auto	Auto	Auto
-----dollars-----															
300	100	3	1,006.71	1,006.71											
320	80	4	1,058.20	1,058.20											
360	120	3	1,147.45	1,147.45										764.89	
400	80	5		1,229.87	1,498.56	1,498.56	819.83							819.83	819.83
	100	4		1,229.87										819.83	819.83
480	80	6			1,704.48	1,704.48	929.65							929.65	929.65
	120	4			1,704.48	1,704.48	923.56							923.56	923.56
500	100	5							957.12					957.12	957.12
560	80	7			1,910.04	1,910.04	1,039.38								1,039.38
600	100	6						2,013.42	1,094.21						
	120	5			2,013.42	2,013.42	1,078.98	2,013.42	1,078.98	1,078.98	1,078.98				1,078.98
700	100	7						2,253.63							
720	120	6						2,294.90		1,234.34	1,234.34	1,234.34	1,234.34		
With Hired Chasers															
300	100	3	877.98	877.98											
320	80	4	920.88	920.88											
360	120	3	1,006.71	1,006.71											
400	80	5	1,092.54	1,092.54										728.29	728.29
	100	4	1,092.54	1,092.54										728.29	728.29
480	80	6			1,498.56	1,498.56	819.83							819.83	819.83
	120	4			1,498.56	1,498.56	819.83							819.83	819.83
500	100	5							844.26					844.26	844.26
560	80	7			1,670.16	1,670.16	911.38							911.38	911.38
600	100	6						1,761.68	957.12					957.12	957.12
	120	5			1,761.68	1,761.68	957.12	1,761.68	957.12	957.12				957.12	957.12
640	80	8			1,841.76	1,841.76	1,002.82							1,002.82	1,002.82
700	100	7						1,979.10	1,072.89						1,072.89
720	120	6						2,013.42	1,094.21	1,094.21	1,094.21	1,094.21	1,094.21		
800	100	8						2,185.08	1,185.60						
840	120	7						2,253.63		1,231.30	1,231.30				
900	100	9						2,359.06							
960	120	8								1,368.38	1,368.38	1,368.38			

a/ Calculated from Milkers Wage Schedule, Table 3 assuming milkers do not clean up.

b/ For one or two milkers as applicable.

c/ Includes adjustments on the base wages delineated in Table 3.

Source: Derived from Tables 2 and 3.

Table 5. Relief Milker Monthly Wage Bill Per Shift: With and Without Hired Chasers, by Milking Herd Size, Housing and Parlor Configurations.^{a/}

Without Hired Chasers														
Milking cows Housing size Housing units			Herringbone								Polygon		Side-Opening	
			Double								24	32	Double	
			5		8		10		12	16			3	4
			Swing	Conv.	Swing	Conv.	Auto	Conv.	Auto	Auto	Auto	Auto	Auto	Auto
300	100	3	203.60	203.60										
320	80	4	213.50	213.50										
360	120	3	230.65	230.65									157.10	
400	80	5		246.50	308.20	308.20	167.65						167.65	167.65
	100	4		246.50									167.65	167.65
480	80	6			347.80	347.80	188.60						188.60	188.60
	120	4			347.80	347.80	187.60						187.60	187.60
500	100	5							194.05				194.05	194.05
560	80	7			383.00	383.00	207.55	407.20	220.45					207.55
600	100	6						407.20	216.05	216.05	216.05			
	120	5			407.20	407.20	216.05	407.20	216.05	216.05	216.05			216.05
700		7						454.30						
720		6						461.30		248.55	248.55	248.55	248.55	
-----dollars-----														
With Hired Chasers														
300	100	3	179.25	179.25										
320	80	4	187.10	187.10										
360	120	3	203.60	203.60										
400	80	5	220.10	220.10									160.45	160.45
	100	4	220.10	220.10									160.45	160.45
480	80	6			308.20	308.20	167.65						167.65	167.65
	120	4			308.20	308.20	167.65						167.65	167.65
500	100	5							172.35				172.35	172.35
560	80	7			329.10	329.10	185.25						182.25	182.25
600	100	6						358.80	194.05				194.05	194.05
	120	5			358.80	358.80	194.05	358.80	194.05	194.05			194.05	194.05
640	80	8			374.20	374.20	202.85						202.85	202.85
700	100	7						400.60	216.35					216.35
720	120	6						407.20	220.45	220.45				
800	100	8						440.20	238.00					
840	120	7						454.30		246.80				
900	100	9						473.70						
960	120	8									273.15	273.15	273.15	

^{a/} Monthly relief wage per shift is calculated from the daily relief wage (Table 3). Monthly relief wage is calculated on a 4.96 and 9.92 day month for single and double milker parlors respectively.

Source: Derived from Tables 2 and 3.

doubled for the two shift operation assumed in this study and then fringes must be added. The employer contributes \$100 per month for each regular milker in addition to cash wages: \$75 to the union health and welfare trust fund and \$25 to the union pension trust fund. The employer FICA tax contribution is 5.85 percent of cash wages.

Milking Center Construction Costs

Physical facilities within the milking center include the milking parlor, wash pen, drip pen, holding pen, milk house, and breezeway. Each of these facilities must be constructed of compatible physical dimension and material. Numerous designs are available for each of the buildings comprising the milking center. However, only one or two designs for each facility are considered in this study. The selected designs are based on observation, expert opinion, and general industry acceptance as "good" designs.^{1/}

Because the milking parlor is the heart of the milking center, specific parlor designs delineate alternative complete milking center designs.

Construction costs for the various buildings that comprise the milking center are summarized in Table 6. In general, these cost estimates were derived from detailed specifications of elemental construction materials, i.e., roof, concrete, walls, fence, etc., given in Appendix Tables A-1 through A-5. Elemental unit construction costs vary widely among dairy contractors as indicated by the

^{1/} In no way should these designs be interpreted as "best". There is no one best design. Specific needs of individual dairymen in conjunction with dairy topography are critical design parameters defining a "best" design for each set of circumstances.

Table 6. Summary of Milking Center Construction Costs: Parlor, Milk House, Drip Pen, Wash Pen, Holding Pen, and Milking Center Total and Annual Costs; by Parlor and Housing Classification.

Parlor classification	Housing classification ^{a/}	Building construction costs					Milking center total cost	Milking center annual cost ^{b/}
		Parlor	Milk house	Drip pen	Wash pen	Holding pen		
-----dollars-----								
<u>Herringbone</u>								
Double 5	FS-80	9,738	14,700	4,110	10,335		38,883	4,258
	FS-100			4,603	12,257		41,298	4,522
	FS-120			5,590	14,066		44,094	4,828
	DL-100			5,096	12,945		43,199	4,730
	DL-120			5,918	15,077		45,433	4,975
Double 8	FS-80	13,506	21,240	4,653	10,771		50,080	5,484
	FS-120			6,328	14,651		55,725	6,102
	DL-120			6,700	15,701		57,147	6,258
Double 10	FS-100	15,199	21,240	5,211	12,871		54,521	5,970
	FS-120			6,328	14,651		57,418	6,287
	DL-100			5,770	13,492		55,701	6,099
	DL-120			6,700	15,701		58,840	6,443
Double 12	FS-120	18,029	21,240	6,328	14,651		60,248	6,597
	DL-120			6,700	15,701		61,670	6,753
Double 16	FS-120	21,813	21,240	6,320	14,651		64,024	7,011
	DL-120			6,700	15,701		65,454	7,167
<u>Polygon</u>								
24	FS-120	17,434	21,240	17,059	27,855		83,588	9,153
	DL-120			17,933	29,396		86,003	9,417
32	FS-120	24,249	21,240	14,994	25,807		86,290	9,449
	DL-120			16,545	27,216		89,250	9,773

(continued)

Table 6 (continued)

Parlor classification	Housing classification ^{a/}	Building construction costs					Milking center total cost	Milking center annual cost ^{b/}
		Parlor	Milk house	Drip pen	Wash pen	Holding pen		
-----dollars-----								
<u>Side-Opening</u>								
Double 3-1	FS-80	12,212	11,752	4,875	10,707		39,546	4,330
	FS-100			5,475	13,316		42,755	4,682
	FS-120			6,375	15,535		45,874	5,023
	DL-100			5,925	14,371		44,260	4,846
	DL-120			6,974	16,340		47,278	5,177
Double 3-2	FS-80	13,538	11,752			8,205	33,495	3,368
	FS-100					9,655	34,945	3,826
	FS-120					11,195	36,485	3,995
	DL-100					10,430	35,720	3,911
	DL-120					12,117	37,407	4,096
Double 4-1	FS-80	13,876	11,752	4,875	10,707		41,210	4,512
	FS-100			5,475	13,316		44,419	4,864
	FS-120			6,375	15,535		47,538	5,205
	DL-100			5,925	14,371		45,924	5,029
	DL-120			6,974	16,340		48,942	5,359
Double 4-2	FS-80	15,411	11,752			8,205	35,368	3,873
	FS-100					9,655	36,818	4,032
	FS-120					11,195	38,358	4,200
	DL-100					10,430	37,593	4,116
	DL-120					12,117	39,280	4,301

^{a/} Free stall (FS) and dry lot (DL) housing have different capacities (see text). Drip pens, wash pens, and holding pens are constructed with capacities determined by the housing configurations.

^{b/} Assumes a 20 year life and CRF = .1095.

Source: Derived from Appendix Tables A-1 through A-5.

ranges reported in these tables. Two major factors are apparently responsible for these variations: material and construction quality varied among contractors, and certain contractors specialized in particular designs or components of the dairy. The design price used to compute facility construction costs was selected as a weighted average to standardize unit costs.

Milking Equipment Investment

Equipment requirements and costs for the various milking parlors considered in this study were synthesized from an itemized breakdown of parlor equipment requirements. Milking equipment suppliers servicing the Chino area provided the detailed information. Equipment specifications included all items comprising the various milking systems, except the refrigeration and milk storage system.

Confidentiality of sources precludes enumeration of all component prices utilized in derivation of milking parlor equipment costs. The milking equipment investment and annual cost of investment for each of the various parlors considered, however, are summarized by major category in Table 7.^{1/} These investment figures reflect high quality, heavy duty equipment. Installation and freight charges are included as separate categories. The total milking equipment investment ranges from \$20,752 for the swinging double 5 herringbone to \$114,189 for the automated 32 polygon

^{1/} The major categories in which the milking equipment investment is summarized are largely self-explanatory. Inclusion of one category, however, requires some justification. The crowd gate is rarely considered an element of milking equipment. A crowd gate is treated as such in this study because it greatly improves milking parlor performance or throughput by promoting cow movement into the parlor.

Table 7. Milking Equipment Costs: Pipeline Equipment, Parlor Equipment, and Installation, by Parlor Configuration.

	Herringbone									Polygon		Side-Opening			
	Double									24	32	Double			
	5		8		10		12	16	3-1			3-2	4-1	4-2	
	Swing	Conv.	Swing	Conv.	Auto	Conv.	Auto	Auto split		Auto	Auto	Auto	Auto	Auto	Auto
	-----dollars-----									-----dollars-----		-----dollars-----			
<u>Pipeline equipment</u>															
Control equipment	530	555	670	756	756	798	798	841	1,514	1,320	1,511	552	552	550	550
Milker units	1,435	2,377	2,178	3,115	3,115	3,906	3,906	4,698	6,230	5,536	6,230	1,174	1,174	1,570	1,570
Vacuum equipment	2,472	2,842	2,720	4,625	4,625	4,697	4,697	6,751	6,911	5,562	9,249	2,782	2,782	2,782	2,782
Milk receiver	1,071	1,071	1,119	1,119	1,119	1,119	1,119	2,228	2,228	2,148	2,237	1,075	1,075	1,075	1,075
1-1/2" stainless	461	461	461	461	461	461	461	461	461	922	922	461	461	461	461
2" stainless	--	--	683	683	683	823	823	1,630	1,791	683	1,365	1,479	1,479	1,618	1,618
2-1/2" stainless	1,264	2,119	1,387	--	--	--	--	--	--	4,577	--	--	--	--	--
3" stainless	--	--	--	3,015	3,015	3,199	3,199	3,264	3,714	--	6,030	884	884	--	--
Miscellaneous equipment	534	534	534	1,408	1,408	1,649	1,649	2,195	2,632	2,371	2,816	--	--	993	993
SUB TOTAL	7,767	9,959	9,752	15,182	15,182	16,652	16,652	22,068	25,481	23,119	30,360	8,407	8,407	9,049	9,049
<u>Parlor equipment</u>															
Stall equipment	4,061	4,061	5,965	8,455	8,455	9,859	9,859	13,462	16,149	14,212	16,909	9,505	9,505	12,006	12,006
Detachers	--	--	--	--	19,648	--	24,613	29,172	38,654	29,569	39,296	7,978	7,978	10,287	10,287
Stimulating stall	--	--	--	--	--	--	--	--	--	--	--	4,590	7,090 ^{a/}	4,590	7,090 ^{a/}
Crowd gate ^{b/}	5,392	5,392	5,392	5,392	5,392	5,392	5,392	5,392	5,392	10,783	10,783	--	--	--	--
SUB TOTAL	9,453	9,453	11,357	13,847	33,495	15,251	39,864	48,026	60,195	54,564	66,988	22,073	24,573	26,883	29,383
<u>Pipeline and parlor</u>															
Equipment total	17,220	19,412	21,109	29,029	48,677	31,903	56,516	70,094	85,676	77,683	97,348	30,480	32,980	35,932	38,432
SALES TAX	1,033	1,165	1,266	1,742	2,920	1,914	3,391	4,206	5,141	4,661	5,841	1,829	1,979	2,156	2,306
<u>Installation</u>	2,500	3,000	3,000	4,000	5,500	4,200	6,200	7,500	9,000	10,000	11,000	5,000	5,500	5,500	6,000
TOTAL INVESTMENT	20,753	23,577	25,375	34,771	57,097	38,017	66,107	81,800	99,817	92,344	114,189	37,309	40,459	43,585	46,738
ANNUAL COST ^{c/}	2,910	3,306	3,558	4,875	8,006	5,330	9,115	11,470	13,996	12,948	16,012	5,231	5,673	6,112	6,554

^{a/} Include \$2,500 for wash stall.^{b/} Extra heavy duty.^{c/} Assumes a 10 year life, 10 percent salvage value and CRF = .1558.

Source: See text.

parlor. Automation and parlor size are primarily responsible for this wide range. The expense of automation is almost exclusively summarized by the "Detacher" category, which consistently accounts for approximately 30 to 40 percent of the total milking equipment investment in automated herringbone and polygon parlors. Automation accounts for a somewhat smaller percentage in side-opening parlors (approximately 25 percent) because the more complex stalls require a greater investment per stall.

The additional expense of automation is apparent when the milking equipment investment of the conventional double 8 herringbone is compared with the automated double 8 herringbone, and the conventional double 10 is compared with the automated double 10 herringbone. Equipment costs increase approximately 64 to 70 percent with the addition of automation to herringbone parlors.

The 24 and 32 polygon parlors have essentially the same milking equipment as the double 12 and 16 herringbone parlors. Major differences in parlor equipment (measured as equipment investment) include the milk line setup, number of crowd gates, and installation and freight requirements. A double loop pipeline is used in conjunction with double 12 and 16 herringbone parlors, whereas the polygon parlors run two complete (separate) lines, one for each side. Yet this difference, as indicated by the "Pipeline" subtotal, is only apparent for the 32 polygon. While two separate lines are used for the 24 polygon, equipment capacity, e.g., line size, may be reduced, thus offsetting much of the additional cost of a separate milk line system. This offsetting capacity adjustment is not available to the 32 polygon. At \$5,391 each, the additional

crowd gate required by the double entry polygon explains a large portion of the difference in total milking equipment investment.

Refrigeration and Milk Storage Equipment Investments

Cost estimates of refrigeration and milk storage equipment are synthesized for the entire system rather than from a detailed equipment component list. Basic system options include: direct expansion cooling with a refrigerated bulk tank, direct expansion cooling with the precooling option of a tube cooler, refrigeration with an ice builder and plate cooler or tube cooler prior to storage in a silo tank.

Four basic criteria determine the appropriate refrigeration and storage systems. First, refrigeration requirements establish the final milk temperature that must be sustained.^{1/} Given the specific milk temperature requirement, the second criteria, gallons of milk produced per hour (parlor throughput measured as milk flow), determines the necessary refrigeration efficiency and capacity. Sufficient daily storage capacity for all milk produced is the third criteria. After these three criteria are met, cost or economy, given comparable performance, is the final criteria.

The refrigeration and milk storage equipment investments corresponding to various milking herd sizes and storage capacities are presented in Table 8. Both the reported range and assumed total system cost estimates are presented. All estimates represent

^{1/} Refrigeration requirements differ among State, Federal, and Creamery regulations. Creamery regulations, designed to extend shelf life, are the most stringent and are used in this study.

Table 8. Milk Storage and Refrigeration Equipment Costs:
Refrigerated Bulk Tank, and Silo Tank with Ice
Builder and Plate Cooler, by Milking Herd Size
and Tank Size.

Refrigerated Bulk Tank (including compressor)				
Milking cows	Tank size	Price range	Design price	Annual cost ^{a/}
	gallons	dollars	dollars	dollars
300	2,000	11,800 - 14,000	13,000	1,823
400	3,000	15,200 - 16,250	15,500	2,173
500	3,500	16,500 - 16,750	16,500	2,314
600	4,000	17,000 - 18,000	17,500	2,454
Silo Tank with Ice Builder and Plate Cooler				
700	5,000	31,000 - 32,000	31,500	4,417
800	6,000	33,000 - 36,500	35,000	4,907
900	7,000	36,000 - 41,500	38,500	5,398
1,000-1,200	8,000	38,650 - 43,000	41,500	5,819

^{a/} Assumes a 10 year life, 10 percent salvage value and CRF = .1558.

Source: Refrigeration equipment manufacturers and suppliers serving the Chino area.

cooling systems based on a creamery requirement of 40 degree milk. Only two basic systems are considered in this study. Direct expansion cooling with refrigerated bulk tanks are utilized up to the 4,000 gallon tank capacity (600 cow milking herd). Beyond that level, direct expansion cooling efficiency is insufficient, and an ice builder and plate cooler refrigeration system with silo storage tank is utilized.^{1/} The specified milking herd size/tank correspondence provides sufficient reserve capacity for daily and seasonal variations. Total system cost estimates were obtained from dealers serving the Chino area.

The Housing Stage

Throughout most of the United States, the primary design consideration in dairy cattle housing is minimization of production losses due to extreme weather. Housing considerations in the Chino area, however, are influenced more by high land values requiring intensive industrialized dairy operations than weather considerations. The mild winters in this area make warm enclosed housing unnecessary, but the hot summer months require construction of shade structures to help maintain milk production. Dairy cattle feed intake is reduced in warm weather, ultimately causing a decline in milk production (Bishop et al., 1969).

Dairy housing facilities must confine cows to the smallest possible amount of land, recognizing that cow comfort, cleanliness, and protection from weather, bodily injury, and disease are necessary ingredients to achieve genetic production capabilities.

^{1/} These two systems represent the principal ones employed in the Chino area.

Design of dairy housing must also integrate well with other stages of dairying and emphasize overall labor efficiency. Dairy housing must act as a feeding center, provide facilities for routine inspections and breeding services, facilitate smooth and rapid cow movement to and from the milking center, and promote efficient waste management.

Insufficient pasture to adequately feed all dry cows makes confinement housing for the total herd essential. Thus, housing cost estimates are for both lactating and dry cows.

Two types of confinement housing facilities and three basic housing unit sizes are pertinent to the Chino production region--dry lot and free stall. Construction cost estimates for 100 and 120 cow dry lot corrals, and double 80, 100, and 120 cow free stall units with adjacent corrals, are synthesized from detailed design specifications presented in Appendix Tables A-6 through A-9. As with the milking center, elemental costs are given both as a range and a design value. Total costs for each of the housing units are not directly comparable. The free stall housing costs represent two complete housing units, including a common feed alley not included in the dry lot estimates. An adjacent corral at 50 square feet per cow is also included in the free stall cost estimates.

Synthesis of total housing costs is somewhat generalized. No attempt is made to delineate all possible housing configurations with each herd size. Instead, this study assumes a single "good" configuration for each herd size. Site or dairy specific situations may dictate better configurations. Illustrations of "typical" dry lot and free stall housing configurations are presented in Appendix Figures A-4 through A-7.

Two basic considerations generally apply to all housing situations, and were used to establish the configurations in this study. First, travel distances from the most distant corral or free stall to the milking center should be minimized. For purposes of this study, it suffices to limit the number of housing units extending away from the parlor to four. Second, given the option to share an alley between two rows of corrals, always share a common feed alley first, and then a common return alley.

Total and annual housing costs for each of the configurations are summarized in Table 9. Total dry lot housing costs were calculated from the single corral or "base" cost estimates, to which the additional cost of water troughs and concrete aprons were added. Costs of feed alleys, cow alleys and cross return alleys connecting the milking center with the corrals were then combined to determine total housing costs for the various herd sizes. Free stall housing costs were computed similarly. However, only cross return alleys are added to the base cost because both feed and cow alleys are included in the initial estimates.

Comparing the corresponding dry lot and free stall total housing cost estimates, it is apparent that free stall housing costs are more than double the cost of dry lot housing. The method of managing wastes would, therefore, be the sole motivation for selecting free stall housing over dry lot housing. This issue is addressed in the waste management stage.

The Feeding Stage

Feed costs average about 60-65 percent of total dairy costs, making feeding an important stage of the dairy operation. Analysis

Table 9. Dry Lot and Free Stall Housing Costs, by Herd Size and Housing Unit Size.

Herd size c/ d/	Housing Unit Size											
	Dry Lot ^{a/}						Free Stall ^{b/}					
	100 cows			120 cows			80 cows			100 cows		
	Number of units d/	Total costs e/	Annual costs e/	Number of units d/	Total costs e/	Annual costs e/	Number of units d/	Total costs e/	Annual costs e/	Number of units d/	Total cost e/	Annual costs e/
375		----dollars----			----dollars----			----dollars----			----dollars----	
400	4	69,862	7,650				5	174,053	19,059	4	171,035	18,728
450				4*	80,134	8,775						
500	5	87,641	9,597				7*	242,689	22,754	5	214,774	23,518
600				5	100,745	11,032	8*	276,018	30,224			
625	7*	120,348	13,177							7*	299,510	32,796
700							9*	311,461	34,105			
750	8*	135,276	14,813							8*	340,694	37,306
800				7*	138,588	15,175	10	345,258	37,806	7*	358,795	39,288
875	9*	153,878	16,850							9*	384,382	42,090
900				8*	156,454	17,132	12*	413,478	45,276			
1,000	10	170,210	18,638							10	426,034	46,651
1,050				9*	177,002	19,382						
1,125	12*	200,847	21,993							12*	511,554	56,016
1,200				10	196,532	21,520						
										10	511,698	56,031

^{a/} Cost estimates include all corral and associated alley costs.

^{b/} Cost estimates include a central return alley and 16 foot cow alleys. All costs are for free stall housing with separate roofs, i.e., with roofs spanning only a single housing unit.

^{c/} Milking plus dry cows.

^{d/} The * indicates housing units with excess capacity in one dry cow unit. The excess capacity results from the simplifying assumption that only housing units of equivalent size are combined.

^{e/} Calculated assuming a 20 year life and CRF = .1095.

Source: See text.

of the feeding stage is divided into two parts. Initially, alternative feeding programs are evaluated. The traditional system of constant level feeding is compared with group feeding. Secondly, materials handling and storage systems corresponding to the specified feeding programs are analyzed. Total feeding costs (the sum of feed costs, materials handling, and storage costs) are then related to herd size.

Analysis of Alternative Feed Programs

Lactating Cow Feed Costs. A linear program which maximizes income from milk sales over feed costs, provides the basic tool to evaluate the economics of alternative feeding systems.^{1/} The program selects concentrate and roughage components and amounts while explicitly considering nutritional requirements for body maintenance, milk production response, butterfat test, maximum voluntary intake of roughage, roughage to concentrate ratio, feed prices, and price received for milk. Specification of milk production response curves and price received for milk enables selection of the optimum level of milk production in addition to ration composition. Maximum income above feed costs is thus achieved by equating marginal revenue from milk with marginal costs of feed.

Three feed programs for lactating cows are modeled. The first program models the conventional method of feeding in the Chino area. A single commercial-mixed, constant level ration is fed in equivalent quantities to all lactating cows. The second program models

^{1/} The use of linear programming formulated least cost feed rations is common practice in the study area.

group feeding with a single commercial-mixed ration fed in different quantities to the various production/lactation groups. The third program models group feeding with a dairy-mixed ration in which bulk commodities are blended on-dairy. Both ration composition and quantity fed vary by production/lactation group.^{1/}

Two feedstuff prices and five milk production response curves are used to model the alternative feed programs. The commercial-mix rations are based on commercial feed prices. The dairy-mix rations are based on bulk concentrate commodity prices which are assumed to be 10 percent below commercial prices. The five response curves chosen reflect 40, 50, 60, 70, and 80 pound maximum daily milk production per cow.

Feed costs are dependent on the milking herd distribution into the alternative production/lactation groups. While herd diversification should theoretically provide the basis of grouping, grouping of cows in this study is restricted by the assumed average annual production per cow of 15,000 pounds. High and low production/lactation groups must be of equal size to approximate the 15,000 pound production level.^{2/} The milking herd distribution into the

^{1/} Proprietary information prevented precise modeling of commercial-mix rations commonly used in the Chino area. Concentrate ration composition and component analysis are maintained in secrecy by commercial feed mills. Consequently, custom blended rations are considered, i.e., rations specified by the dairyman--in this case rations that maximize income over feed costs--with feedstuffs purchased from and mixed by a commercial feed mill.

^{2/} Because of the specific production curves chosen, average production exceeds the 15,000 pound limit even under the assumption of equivalent high and low production/lactation group sizes. Thus, each group is indexed to ensure the 15,000 pound assumption is satisfied. This indexing causes a small upward bias in the feed costs since a higher energy ration is fed than optimally required. Relationships among alternative feed programs, however, are unaffected.

alternative production/lactation groups is then determined by herd size in conjunction with corral size.

The distribution of a milking herd into three and four production/lactation groups for the various corral numbers considered in this study is presented in Tables 10(a) and (b). Recall the earlier discussion of the milking center/housing correspondence. The number of corrals for a particular herd size and corral size were uniquely specified. The distributions shown in Tables 10(a) and (b) similarly correspond to these milking herd and corral sizes.

Daily feed costs for lactating cows are summarized in Table 11 by feed program and herd distribution. Feed costs are presented on a daily composite cow basis, which is representative of the daily cost to feed an average lactating cow in the herd. Table 11 is divided by feed program classification, i.e., dairy-mix variable ration, commercial-mix variable ration, and commercial-mix constant ration. Accordingly, feed cost estimates are based on bulk commodity prices and commercial feed mill prices. Column headings under the commercial mix program indicate the particular ration fed. For example, 80 identifies the ration for the 80 pound response function (i.e., the optimum ration for a cow producing 80 pounds of milk per day) fed in various amounts to the specified production/lactation strings. The first six rows of Table 11 identify the various milking herd distributions. Elements under the "production/lactation" column headings are obtained by multiplying the given string percentage by the associated daily feed costs for a single cow. Summing over the production/lactation strings yields "total" feed costs for the composite cow. Elements of the seventh and final row are average feed costs over each of the various milking herd distributions.

Table 10. Distribution of the Milking Herd into Three and Four Production/Lactation Groups, by Number of Corrals and Daily Production.

3 Production/Lactation Groups				
Number of milking herd corrals	Daily milk production			
	80 pounds	60 pounds	40 pounds	
	-----proportions-----			
3, 6, 9	.333	.333	.333	
4, 8	.25	.50	.25	
5	.20	.60	.20	
7	.286	.428	.286	
4 Production/Lactation Groups				
Number of milking herd corrals	Daily milk production			
	80 pounds	70 pounds	50 pounds	40 pounds
	-----proportions-----			
4, 8	.25	.25	.25	.25
6	.166	.333	.333	.166

Table 11. Daily Feed Cost Per Composite Lactating Cow, by Feed Program and Milking Herd Distribution.

Milking herd distribution by daily milk production					Dairy-mix bulk commodities	Commercial-mix			
						Variable ^{b/}			Constant ^{c/}
80 pounds	70 pounds	60 pounds	50 pounds	40 pounds	Variable ^{a/}	80 pounds	70 pounds	60 pounds	60 pounds
-----proportions-----					dollars	-----dollars-----			dollars
.333	0	.333	0	.333	1.930	2.03	2.03	2.03	2.09
.25	0	.50	0	.25	1.920	2.03	2.01	2.01	2.06
.20	0	.60	0	.20	1.920	2.02	2.00	2.00	2.04
.286	0	.428	0	.286	1.930	2.03	2.02	2.02	2.07
.25	.25	0	.25	.25	1.930	2.04	2.03	2.03	2.07
.166	.333	0	.333	.166	1.920	2.03	2.01	2.01	2.04
Average					1.925	2.03	2.02	2.06	2.06

^{a/} Both ration composition and quantity fed vary according to production/lactation group.

^{b/} Ration composition (defined by the specified milk production response function) is fixed, but quantity fed to alternative production/lactation groups varies. For example, the 80 pound column identifies the ration for the 80 pound response function, i.e., the optimum ration for a cow producing 80 pounds of milk per day. However, this ration is fed in variable quantities according to the nutritional requirements of the alternative production/lactation groups.

^{c/} Both ration composition and quantity, defined by the 60 pound production/lactation response function, are fed equivalently to all groups.

Source: See text.

A comparison of the lowest average composite cow feed costs among the alternative feed programs identifies the dairy-mix program as most efficient at \$1.925 per cow per day, followed by the commercial-mix program at \$2.02 and the constant ration program at \$2.06. Note that under the commercial-mix program, the 60 and 70 pound rations yield the same daily feed cost. The equivalent costs may be explained by the comparable ration composition and nutrient analysis (see Matulich, 1976, Appendix B). In reality, the 70 pound ration yields a slightly lower daily feed cost than the 60 pound ration. Rounding errors, however, eliminate the differences. The \$.135 cost differential between the dairy-mix and constant ration feed programs, and the \$.095 differential between the dairy-mix and commercial-mix program are somewhat deceiving. These differences reflect the 10 percent price differential between bulk commodities and commercial mill feeds, in addition to more efficient feed utilization. With the exception of the constant ration, milking herd distribution is observed to have only a modest effect on feed cost.

Dry Cow Feed Costs. Dry cow nutritional requirements are less demanding than that of lactating cows, as the objective of dry cow feeding is body maintenance rather than production. Consequently, feed energy content may be reduced and concentrates eliminated from the diet. The resultant feed requirement is between 25 and 30 pounds of alfalfa per dry cow per day. Assuming an average level of 28 pounds of hay per day at \$72 per ton, the cost of dry cow feed is one dollar per day per cow or \$365 per year.

Combined Annual Feed Costs. Annual feed costs per cow are computed on the relative percent of time a cow is lactating and dry. Hence, annual feed costs per cow equal daily lactating cow feed

costs times 365 days times 80 percent, plus daily dry cow feed costs times 365 days times 20 percent. Annual feed costs for the dairy-mix, 70 pound commercial-mix and constant rations are \$635, \$663, and \$675 per cow respectively. The dairy-mix program reduces annual total herd feed costs below the conventional constant ration program by \$15,000 for the 375 cow herd, and \$48,000 for the 1,200 cow herd.

The conclusion that the dairy-mix feed program is most efficient is based solely on cost of feed, irrespective of dairy size considerations. While the greatest portion of the feeding system cost is the cost of feed, an effective feeding system is also dependent on feed storage, materials handling, and in the case of production/lactation feeding, string management. Unit costs for each of these latter components are decreasing functions of herd size. Furthermore, total cost of feed storage and materials handling equipment is greatest for the dairy-mix program and least costly for the constant ration program. It is, therefore, conceivable that below some minimum milking herd size, the least cost ranking of the alternative feed programs changes.

To test the hypothesis that efficient group feeding is a function of herd size, annual costs are compared among the alternative feeding programs for each milking herd size. Feed storage, feeding equipment, and managerial and labor costs are added to annual feed costs for each of the alternative feed programs. Common cost components within each of these cost categories are treated as mutually offsetting.^{1/}

^{1/} Allowing common cost components to offset each other avoids the problem of allocating certain factor costs on a stage or task basis. For example, within a particular herd size, a tractor of equivalent
(footnote continued on next page)

Feed Storage Costs

Storage facilities differ between the variable ration feed program in which bulk commodities are mixed on-dairy and the other two feed programs in which premixed commercial mill rations are purchased. Bulk commodity storage requires construction of a feed shed to segregate each feedstuff. Premixed rations are stored in metal feed tanks.

A feed shed resembles a pole barn enclosed on three sides and divided lengthwise into six cells. The shed structure is wooden with a corrugated sheet metal roof. The floor area is surfaced with a four inch concrete slab to keep feeds clean and dry. A six inch concrete slab abutting the shed floor provides an all-weather unloading platform for feedstuff delivery vehicles. Overall feed shed size is dependent on storage capacity and herd size. Three shed sizes representing approximately two to three months storage capacity correspond to three herd size ranges. Construction cost estimates for each of the three shed sizes are presented in Appendix Table A-10. Total cost is estimated at \$6,392 for the 375-624 cow range, \$7,990 for the 625-999 cow range, and \$9,588 for the 1,000-1,200 cow range. Annual costs are \$630, \$787, and \$945 respectively.

Cost of conventional metal feed tanks is based on holding capacity. Since the average capacity of commercial feed mill

(footnote 1 continued from previous page)

size is employed for approximately the same amount of time in all feeding programs. Furthermore, that same tractor is employed in other nonfeeding related jobs. Rather than allocating tractor costs for the proportionate time used in the feeding operation, tractor costs for the feeding stage are allowed to cancel. Total tractor costs are later evaluated in the dairy equipment section.

delivery trucks is approximately 20 tons, a standard 25 ton feed tank is considered in this study. Price quotes from feed tank manufacturers ranged from \$2,100 to \$2,550 per 25 ton tank. A price of \$2,300 was selected as representative. The number of tanks required per dairy is a function of herd size, average quantity of concentrate fed per cow per day, and inventory requirements.^{1/} Given an average daily concentrate requirement per cow of about 28 pounds, tank costs are estimated at \$2,300 for the 375-446 cow range, \$4,600 for the 447-874 cow range, and \$6,900 for the 875-1,200 cow range. Annual costs equal \$267, \$453, and \$680 respectively.

Traditionally, baled hay is stored in stacks, either unprotected from weather or protected by a pole barn. Bales are loaded on a hay wagon and delivered to the manger. Recently, however, more dairies are having their hay stored where it is grown, and laid out one load at a time at the manger. This saves handling bales at least once. Other advantages include lower fire insurance and lower taxes on hay. This latter baled hay storage method is utilized in this study.

Feeding Equipment Cost

Alternate feeding equipment complements are required for the various feed programs. A tractor drawn self-unloading feed wagon is required for the constant commercial-mill premixed ration. Group feeding under the commercial-mixed variable ration program

^{1/} Total storage capacity should provide for a 5 day feed supply, avoiding problems encountered in feed delivery scheduling during holidays.

similarly requires a tractor drawn self-unloading feed wagon for feed delivery. However, precise control of quantities fed to the various groups requires weigh scales be added to the trailer chasis. A self-unloading truck-mounted mixer box with weigh scales is required under the dairy-mix variable ration program, in which bulk commodities are tractor loaded and mixed on-dairy.

Total feeding equipment requirements and costs are presented by herd size in Table 12. Total feed delivery equipment costs range from \$3,000 for a self-unloading wagon to over \$31,000 for the largest truck-mounted feed mixer. Annual feeding equipment costs are given in column 3 of Table 12.

Additional Managerial and Labor Costs

Production/lactation grouping of cows incurs managerial and labor costs in addition to those of the conventional feed program.^{1/} Which cows belong in a particular string, and when cows should be moved from one string to another, are critical managerial decisions required under a group feeding program. Current and historical production, calving dates, and breeding and health records are very important inputs into stringing decisions. Hence, the Dairy Herd Improvement Association (DHIA) barn sheet, supplemented with other dairy records form the basic decision making tools. Moving cows to different strings is greatly aided by lock stanchions at the feed manger. Cows are easily isolated and moved during routine

^{1/} It is assumed that the time required to feed cows is the same for each feeding program. In reality, feed time under the dairy-mix program is greater than either of the alternatives. The difference is modest, however, and no attempt is made to estimate the additional labor requirements or cost.

Table 12. Feeding Equipment Costs for Herds Less Than 750 Cows and Between 750 and 1,200 Cows.

Less Than 750 Cow Herd Size			
	Purchase price	Life	Annual cost ^{b/}
	dollars	years	dollars
<u>Feeding equipment (options)^{a/}</u>			
1 Self unloading wagon	3,000	10	420
1 Self unloading wagon with scales	5,500	10	771
1 Truck mounted mixer	26,000	10	3,646
Mixer box with scales (350-380 cu. ft.) 11,000			
Truck 15,000			
750 to 1,200 Cow Herd Size			
<u>Feeding equipment (options)^{a/}</u>			
1 Self unloading wagon	3,500	10	491
1 Self unloading wagon with scales	6,000	10	841
1 Truck mounted mixer	31,000	10	4,347
Mixer box with scales (400 cu. ft.) 14,000			
Truck 17,000			

^{a/} Select only one feeding option in calculating total equipment costs.

^{b/} Assumes a 10 percent salvage value and CRF = .1558.

Sources: Dairy equipment suppliers in the Chino region.

breeding and health inspection. The occasional cow that fails to get locked in the stanchion can be isolated in the parlor catch pen.

Additional managerial and labor requirements are specified by herd size in Table 13. All estimates are based on biweekly restraining practices. Because group feeding is not widely practiced, estimates of additional managerial and labor requirements and cost should be regarded as preliminary.

Selection of Feeding Programs

Inclusion of feed storage, feeding equipment, and additional labor and managerial costs with the annual cost of feed, does not alter the feed program ranking observed for feed cost only. Annual distributional and storage costs for the 375 and 1,200 cow herds respectively, range from \$4,880 to \$6,642 for the dairy-mix program, \$1,642 to \$2,871 for the commercial-mix program, and \$687 to \$1,171 for the constant ration program. In spite of the fact that storage and distributional annual costs are considerably greater for the dairy-mix program, differences in annual cost of feed between the alternative programs are not offset.^{1/} Total annual feed system costs remain lowest for the dairy-mix program for all herd sizes considered in this study. Hence, future reference to cost of feeding refers to the dairy-mix program for all herd sizes.

The Waste Management Stage

Waste management was defined as consisting of the four functional elements: collection, transportation, treatment, and

^{1/} Feeding silage as part of the ration is not considered in this study. Blending silage with concentrates would increase feed distribution costs.

Table 13. Additional Management and Labor Requirements and Costs for Group Feeding, by Herd Size.

Herd size	Managerial requirements <u>a/</u>	Wage rate <u>b/</u>	Additional annual management cost	Labor requirements <u>a/</u>	Wage rate	Additional annual labor cost	Total annual cost
	hours per month	dollars per hour	dollars	hours per month	dollars per hour	dollars	dollars
375-624	2.0	6.70	161	10 ^{c/}	3.70	444	605
625-999	3.8	7.50	342	16	3.70	710	1,052
1,000-1,200	4.2	8.30	418	21	3.70	932	1,350

a/ Estimates derived from private conversations with Mr. Shirl Bishop and Dr. Don Bath.

b/ Derived from monthly salary assuming \$1,200 per month for 375-624 cow range, \$1,350 per month for 625-999 cow range, and \$1,500 per month for 1,000-1,200 cow range.

c/ All labor in the 375-499 cow range is provided by the Herdsman. For this range, the 10 hours per month outside labor requirement must be provided by the Herdsman. No attempt is made in this study to analyze the feasibility of the Herdsman providing the necessary labor.

Source: See text.

disposal. Direct disposal, however, composed of the subset of collection, transportation, and disposal is necessary and sufficient to manage wastes. The functional element of treatment prior to disposal is important because it offers the advantages of volume reduction, stabilization, and resource recovery. Volume reduction may reduce system costs because transportation and disposal costs are a direct function of waste volume. Stabilization minimizes possible deleterious environmental effects of dairy wastes. Resource recovery and utilization of dairy wastes offers the potential to offset waste management costs. In this study only those processes that satisfy constraining environmental quality objectives and offer resource recovery capabilities are considered.

Functional Element Alternatives

There are alternative methods available for each waste management element. We restrict the set considered by element to those which offer the best potential for meeting the objectives of the study. Then elements are combined to form waste management system alternatives for the stage. Alternatives considered for each element follow.

Collection: Collection methods are classified as either flush-out (liquid) or scrape-out (solid). The method utilized in a waste system is dependent on housing and the treatment method utilized.

Transportation: Two transportation methods are considered. Solids transportation costs are estimated for 10 and 24 ton trucks. While three alternative liquid conveyance systems are available, costs are estimated only for a gravity flow conveyance system. An

expanded discussion of the transportation function is presented in Matulich (1976, pp. 193-195).

Treatment Process: Four treatment processes were selected as having "good" volume reduction, stabilization, and resource recovery capabilities.^{1/} Three of these, composting, anaerobic digestion, and refeeding, are biological processes while the fourth, incineration, is a physical/chemical process. Each is depicted as a component of the general dairy waste management system in Figure 2 and is discussed briefly below.^{2/}

Composting is a biological stabilization process in which the organic content of raw waste is partially stabilized prior to land application. Volume reduction, concentration of plant nutrients, and increased water holding capacity are characteristics of composted manure. Commercial composting operations in the Chino Basin have proven to be an effective waste management alternative. Although composting technology is well advanced, market development is a serious limitation to widespread use of composting.^{3/}

Anaerobic digestion is a liquid waste treatment process in which organic matter is stabilized biologically in the absence of oxygen. Methane gas, which is produced during organic degradation

^{1/} A discussion of dairy manure and waste water characteristics is presented in Appendix C. These characterizations are utilized as basic design parameters for the alternative treatment and disposal methods and means considered in this study.

^{2/} For a more complete discussion, see Matulich (1976, pp. 97-128).

^{3/} Currently, about 20 percent of the manure in the Chino Basin is hauled to compost companies (A. A. Webb, 1974). The extent to which the market for composted dairy manure can be expanded is unknown. Given the concentration of mineral salts, transportation costs of this bulky material, and available substitute products, the outlook for significantly improved markets is not promising. (It is assumed in this study that no more than 20 percent of the dried manure in the Basin may be composted.)

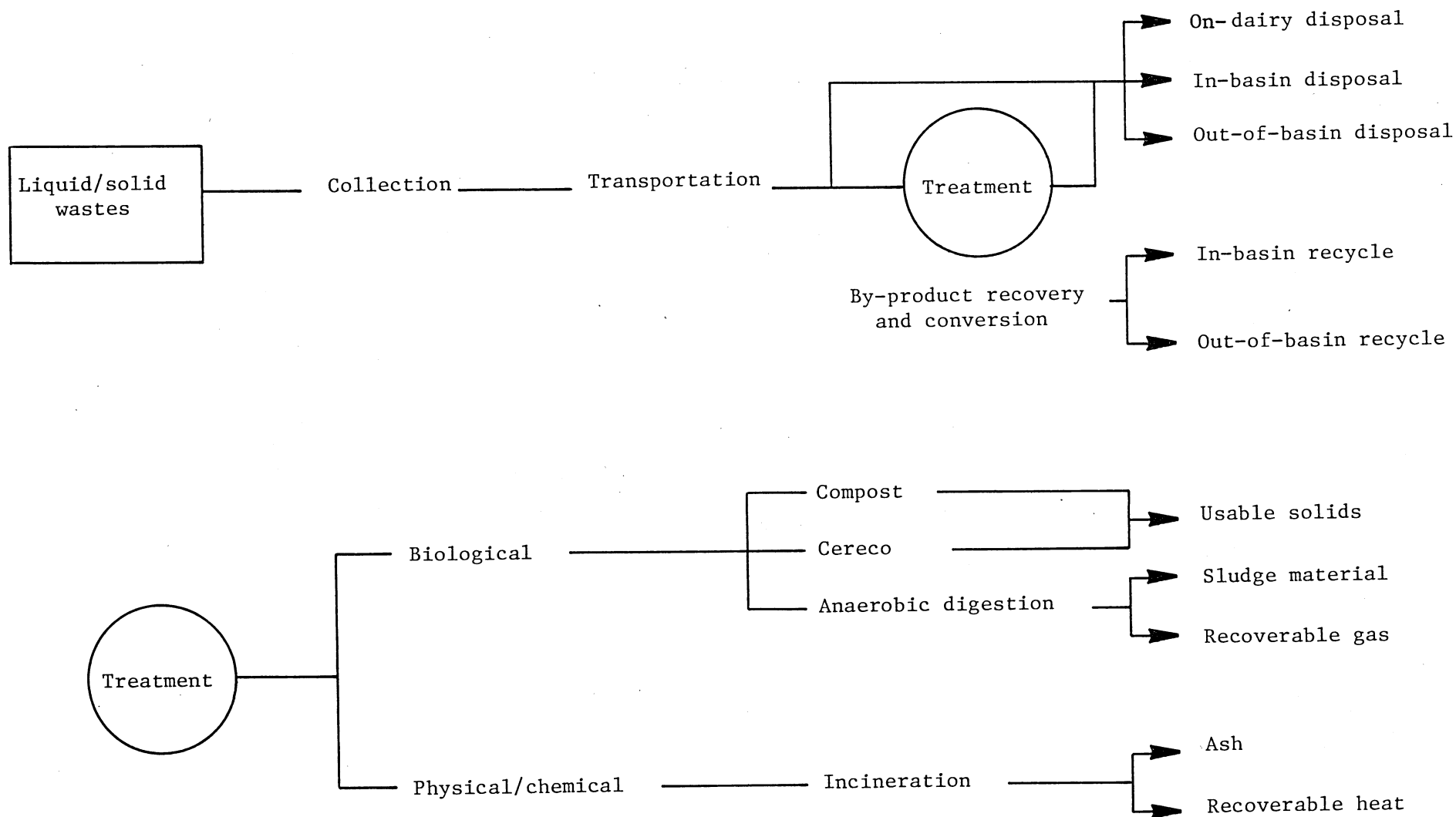


Figure 2. The General Dairy Waste Management System.

and stabilization, can be recovered and utilized to produce electricity. Anaerobic treatment methods are either unmanaged anaerobic lagoons (common to livestock operations) or controlled complete-mixed reactors (common to municipal treatment). This latter system, in which temperature and mixing are controlled to promote optimum conversion and production of methane, is analyzed in this study.^{1/}

Incineration is a process of burning combustible matter under controlled conditions. Originally designed to reduce waste to inert substances, waste-heat recovery has become an important design consideration in an effort to capture the energy contained in wastes. Both conventional refractory wall incinerators and waterwall incinerators may be used for heat recovery. However, only waterwall units are evaluated in this study because of reduced volumetric capacity and required equipment to control air pollution from exhaust gasses and particulate matter.

Refeeding manure to animals offers a promising new extension of material recovery. Many of the original nutrients available in the dairy ration escape digestion. Processing the manure can enhance the nutritional value of waste by increasing the availability and/or concentration of protein and energy. Furthermore, processing can control ingestion of hazardous substances such as heavy metals, pesticides, drugs, and pathogens that may be present in the manure.

^{1/} Digester costs were estimated under two alternative loading rates: 0.2 and 0.4 pounds of volatile solids per cubic foot (lbs. VS/cu. ft.) of digester capacity. A discussion of the effect of the alternate loading rates is presented in Matulich (1976, pp. 195-205).

Although three basic manure refeeding process technologies are available, only the "Cereco Process" is evaluated in this study.^{1/}

By-product recovery equipment is included as an essential element in the liquid and thermal treatment processes. Only in the material recovery processes, composting and refeeding, are the recovered by-products in final consumption form.^{2/} Recoverable by-products from the liquid and thermal treatment processes require conversion to directly consumable products. Both steam and gas are converted to electricity, put into the existing electrical grid, and sold to the local power company. Distributional problems encountered in utilizing the recovered by-products in other forms are thereby minimized.

Disposal: Each of the treatment methods discussed above, with the exception of composting, requires disposal of some portion of the initial waste. The disposal alternatives are sanitary landfilling of solids, and submarine disposal of liquid waste via the Santa Ana Regional Interceptor. Only sanitary landfilling, however, may be used for disposal without prior processing. Spreading manure

^{1/} The Chino Basin Municipal Water District, in conjunction with the Ceres Ecology Corporation, is building a Cereco Process plant facility capable of processing the manure from 10,000 cows.

^{2/} Materials recovery from the Cereco Process poses a special analytical problem. Recovery of materials is hampered by market limitations. Although multiple potential markets exists for the recovered materials, the extent of demand for each market is unknown. Development of reasonably accurate by-product revenue estimates is problematic in the absence of price information. Alternative cost-revenue situations are therefore considered to evaluate potential process performance.

on pasture is an on-dairy disposal method without prior processing, but adherence to water quality objectives limits the loading rate.^{1/}

Waste Management Cost Estimates

The procedure used to estimate waste management costs differs from that followed in the other stages. The necessity of combining elements and, in some cases, using a combination of alternatives within a functional element, results in total waste system cost estimates. Since the off-dairy treatment costs are for large-scale systems, costs are allocated to the individual dairy as per cow user costs. Some treatment alternatives yield energy or other products which are used to offset system costs.

Collection Costs

The interaction between the dairy production system and the waste management stage is evident in waste collection. Housing design must be closely coordinated with waste management practices. The flow of wastes to ultimate disposition is depicted in Figure 3 as a function of housing. Free stall housing is shown to complement both liquid and solid treatment/disposal methods, whereas dry lot housing is compatible only with solid treatment/disposal methods. Accordingly, the collection methods are classified as either flush-out (liquid) or scrape-out (solid) techniques. A discussion of

^{1/} In the context of this study, spreading is permitted only on dairy owned or controlled pasture, and limited by current discharge regulations to the manure from approximately 1.5 cows per acre per year. Assuming dairies own or control one acre for every 20 cows, there are approximately 8,350 acres available for manure spreading. This is equivalent to manure from 12,525 cows at the prescribed loading rate or approximately 7.5 percent of the 1976 Chino Basin dairy cow population.

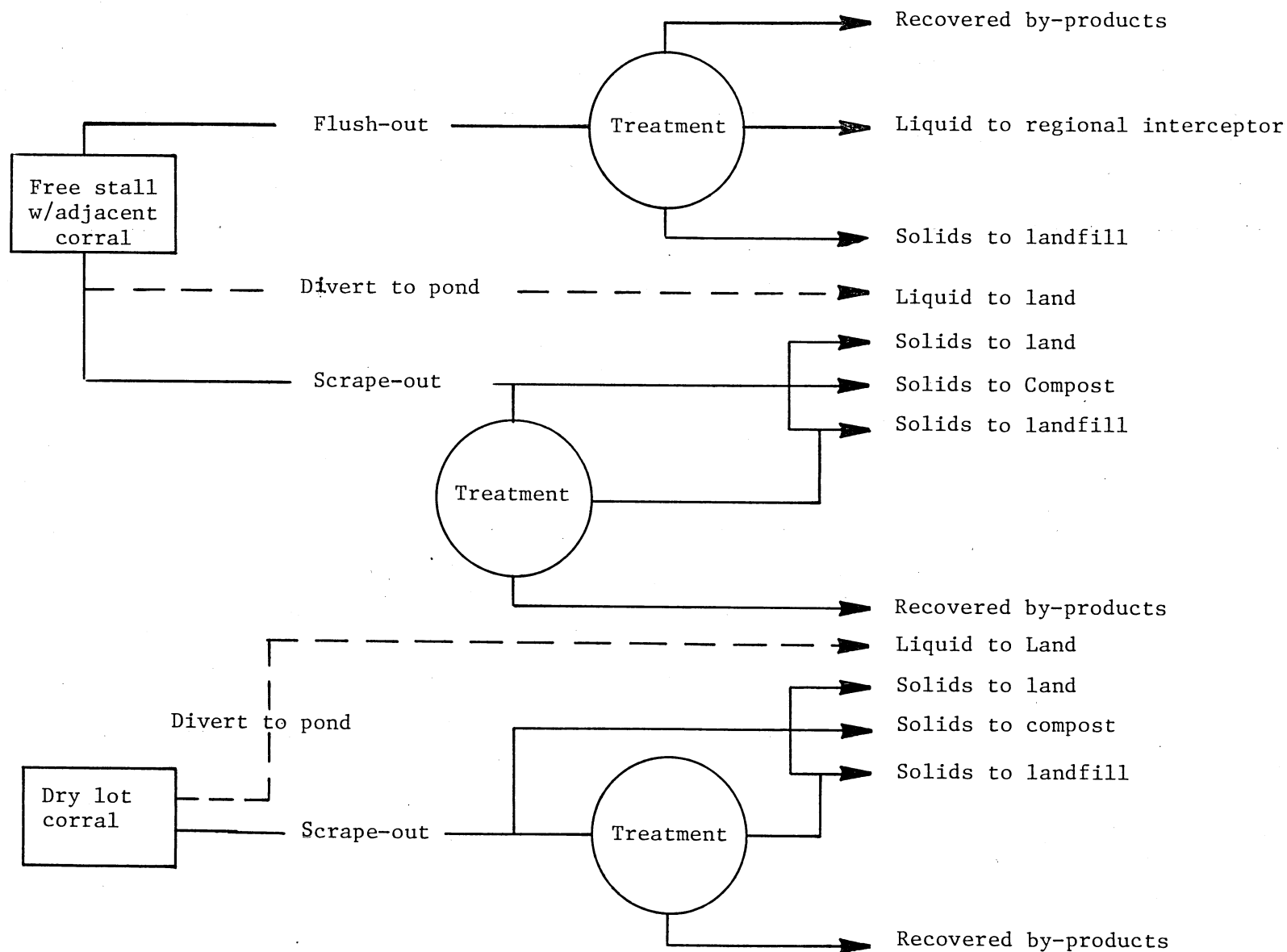


Figure 3. General Waste Flows to Ultimate Disposition, by Housing Type.

coordination of collection with waste treatment/disposal methods follows.

Incineration, Sanitary Landfill, Composting, and Spreading.

Each of these treatment/disposal methods utilize naturally dried manure. Thus, each method shares a common housing design (dry lot corrals) and uses the same collection functions. Solid manure deposited on the corral surface is allowed to accumulate approximately six months prior to collection. Commercial corral cleaners remove the accumulated manure from the corrals in late summer and spring. The manure is then transported directly to disposal or to treatment prior to disposal.

Estimates of corral cleaning charges are developed from a survey of the major commercial corral cleaners and manure haulers serving the Chino dairy community. Charges for commercial corral cleaning average \$1.00 to \$1.20 per ton of manure removed. Given an estimated 3.65 tons of corral scraped manure per cow per year and assuming a cleaning charge of \$1.10 per ton, the on-dairy adjustment cost totals approximately \$4.00 per cow per year.

Cereco Process. On-dairy adjustments associated with the Cereco Process depend on the proportion of basin wastes processed by this method. Two capacities are modeled: 160,000 cows which would satisfy off-dairy treatment/disposal requirements for the basin and 80,000 cows which is about one-half of total treatment/disposal requirements.

The Cereco Process utilizes only fresh manure deposited on concrete. Essentially all manure is deposited on concrete with free stall housing, whereas only one-half the manure is deposited on concrete with modified dry lot housing. Free stall and dry lot housing,

therefore, combine with the Cereco 160,000 and 80,000 methods respectively.

Although the nature of on-dairy adjustments is similar, the specific adjustments differ according to housing design. Under the free stall-Cereco 160,000 system, additional labor is required to scrape the free stall alleys daily. This additional daily labor requirement is estimated to be 15 minutes per free stall housing unit, or equivalently, 90 hours per year.^{1/} At \$3.55 per hour, the annual labor cost totals \$320 per free stall housing unit. In addition to the above adjustment in labor, a bunker with seven day storage capacity must be constructed. Bunker construction costs are estimated at \$11,000 for herds less than or equal to 750 cows and \$19,000 for herd sizes between 750 and 1,200 cows.^{2/} On an annual basis, assuming a 20 year life and 9 percent interest, bunker costs equal \$1,205 and \$1,971 for herd sizes less than or equal to 750 and greater than 750 cows respectively.

The small quantity of concrete in dry lot housing poses a special managerial problem for the Cereco 80,000 system. The cow alley must be modified to capture one-half of the wastes on concrete (Chang, Adriano, and Pratt, 1973 and private conversations with Chang and Bishop, 1975). The required modifications involve widening the cow alley two feet and placing a fence behind the cow

^{1/} Estimates of additional labor required to clean concrete alleys were obtained from conversations with dairymen in the Chino production region and elsewhere.

^{2/} Bunker construction cost estimates are not well developed. Preliminary estimates were obtained from the Chino Basin Municipal Water District and from Shirl Bishop.

alley with gates at either end.^{1/} Construction cost estimates for the cow alley modifications are detailed in Appendix Table A9 for 100 and 120 cow corrals. Additional annual cow alley costs for each 100 and 120 cow corral are \$160 and \$182 respectively. The dry lot-Cereco 80,000 system also requires a bunker with 7 day storage capacity and additional labor to scrape out the alley. Because only one-half of the manure is deposited on concrete with dry lot housing, dry lot bunker costs are one-half of the free stall bunker costs. Hence, annual bunker costs equal \$603 and \$986 for herd sizes less than or equal to 750 and between 750 and 1,200 cows respectively. The additional daily labor requirement is estimated to be only 10 minutes per corral because total alley area is less, and the dry lot housing layout is more convenient for alley scraping than is free stall housing. On an annual basis, this additional labor requirement is equivalent to 60 hours or \$213 per corral per year.

In addition to on-dairy adjustments in support of the Cereco 80,000 system, the remainder of manure must be removed from the earthen loafing area. The associated on-dairy adjustment is similar to that discussed under Incineration, Sanitary Landfill, Composting, and Spreading. The naturally dried manure is collected by commercial corral cleaners at an annual cost of \$2.00 per cow.

The Liquid Waste Stream. Until now, managing the liquid waste stream in a scrape-out system has been dealt with only briefly. Each of the scrape-out systems must be supplemented with a separate liquid waste management system. The liquid waste management system

^{1/} The extended concrete cow alley and rear fence increases the amount of time cows stay on concrete near the feed.

consists of ponding prior to land application. Waste holding ponds offer two important management advantages: they promote partial biological stabilization of organic wastes, and more importantly, they provide a temporary storage facility that augments the natural assimilative capacity of the environment through timing of ultimate disposal. Liquid waste-flows from the milking operation and runoff from the housing facilities may be stored during rainy periods when pasture is saturated. Subsequent disposal minimizes runoff.

Although management of waste holding ponds is an important element in the overall dairy waste management program, little attention is devoted to the cost of such practices in this study. Unlike existing dairies that are required by recent discharge regulations to specifically construct holding ponds, new dairies modeled in this study obtain such facilities at essentially no cost.^{1/}

Anaerobic Digestion. The nature of flush-out waste collection is quite different from the previously discussed scrape-out techniques. Unlike the scrape-out techniques, flush-out collection is capital intensive, requiring only modification to the housing system. No labor is involved in flush-out collection of dairy wastes. Water recovered from the cow and barn washing, and refrigeration operations is released periodically to flush manure from the housing area. Because virtually all manure is deposited on concrete, free stall housing is ideal for a flush-out system.

^{1/} An earthen holding pond is excavated from fill dirt utilized in general dairy grading. Costs of supportive equipment, principally pumps and specialized diversion equipment, are relatively small on an annual basis. Furthermore, pond management incurs little additional labor costs. Irrigation costs are included in the general labor wage bill. Thus, the cost of managing waste holding ponds is omitted from this analysis.

The specific modifications to free stall housing depend upon the particular type of flushing technique. Numerous flush-out alternatives are available including a reservoir and dam at the head of each alley, a central holding tank with arteries to each alley, or a pressurized system. Each of these techniques is advantageous under certain conditions. Since the technique and optimal design should be engineered for the specific dairy situation, the cost estimates developed in this study are generalized and should be considered as representative only.

Flush-out collection system costs are estimated to be \$2,000 per free stall housing unit, which includes the cost of water collection and impoundment, any delivery lines including necessary footings and valves, and any other miscellaneous equipment and facilities. Assuming a 20 year life and 9 percent interest, annual cost per free housing unit is \$219.

Transportation Costs

Costs are estimated for transportation of solid wastes by truck and liquid wastes by gravity flow conveyance systems. Estimated truck transportation costs for solid wastes used in this study are shown in Table 14. On a dollar per ton basis, transportation costs for a 24 ton truck are approximately one-half of those for a 10 ton truck.

Liquid waste conveyance system estimates are derived from A. A. Webb (1974). Webb estimated total costs for two gravity flow conveyance systems: one sized to existing peak flow, the other for twice the existing peak flow. The larger system was considered in the event that the dairy industry relocated in the future. A

Table 14. Waste Transport Costs for 10 and 24 Ton Haul Vehicles, by Haul Distance and Average Speed.

10 Ton Truck							24 Ton Truck						
Truck (capital cost)				\$25,000.00			Truck (capital cost)				\$50,000.00		
5 year life at 9 percent (0.25709-CRF)				\$ 6,427.00			5 year life at 9 percent (0.25709-CRF)				\$12,855.00		
Truck per hour (40 hour week)				\$3.09 (6,427.00/52x40)			Truck per hour (40 hour week)				\$6.18 (12,855.00/52x40)		
Driver (including benefits)				\$15.00 per hour			Driver (including benefits)				\$15.00 per hour		
Truck O & M				\$0.15 per mile			Truck O & M				\$0.20 per mile		
Distance		Average speed	Duration	Cost per load ^{a/}					Cost per ton	Cost per cow			
One way	Round trip			Driver and truck	Operation and Maintenance	Hauling	Overhead, profit, and downtime	Total cost per load		Landfill at 3.65 tons/yr. ^{b/}	Incineration at .73 tons/yr. ^{c/}	Digestion at 2.3 tons/yr. ^{d/}	Digestion at 2.5 tons/yr. ^{e/}
---miles---		mph	hours	-----dollars-----			-----dollars-----						
8	16	25	.64	11.58 (13.56)	2.40 (3.20)	13.98 (16.76)	3.50 (4.19)	7.48 (20.95)	1.75 (.87)	6.39 (3.18)	1.28 (.64)	4.03 (2.01)	4.38 (2.18)
15	30	25	1.20	21.71 (25.42)	4.50 (6.00)	26.21 (31.42)	6.55 (7.86)	32.76 (39.28)	3.28 (1.64)	11.97 (5.99)	2.39 (1.20)	7.54 (3.77)	8.20 (4.10)
20	40	28	1.42	25.69 (30.08)	6.00 (8.00)	31.69 (38.08)	7.92 (9.52)	39.61 (47.60)	3.96 (1.98)	14.45 (7.23)	2.89 (1.45)	9.11 (4.55)	9.90 (4.95)
25	50	30	1.66	30.03 (35.16)	7.50 (10.00)	37.53 (45.16)	9.38 (11.29)	46.91 (56.45)	4.69 (2.35)	17.12 (8.58)	3.42 (1.72)	10.79 (5.41)	11.73 (5.86)
30	60	32	1.87	33.83 (39.61)	9.00 (12.00)	42.83 (51.61)	10.71 (12.90)	53.54 (64.51)	5.35 (2.69)	19.53 (9.82)	3.91 (1.96)	12.31 (6.19)	13.38 (6.73)

^{a/} Numbers without parentheses refer to costs for a 10 ton truck; numbers with parentheses refer to costs for a 24 ton truck.

^{b/} Corral scrapings at 30 percent moisture content total 3.65 tons/cow/year.

^{c/} Weight of incinerator ash is .73 tons per cow (20 percent x 3.65 tons).

^{d/} Sludge (30 percent moisture content) from digesters loaded at the 0.2 lbs. VS/cu. ft. totals 2.3 tons/cow/year

$$\left[\frac{.15}{.85} + .85(1-.45) \right] \times 20 \text{ lbs.} = 12.6 \text{ lbs./day} \times 365 \text{ days} = 2.3 \text{ tons/year.}$$

^{e/} Sludge (30 percent moisture content) from digesters loaded at the 0.4 lbs. VS/cu. ft. totals 2.5 tons/cow/year

$$\left[\frac{.15}{.85} + .85(1-.40) \right] \times 20 \text{ lbs.} = 13.6 \text{ lbs./day} \times 365 \text{ days} = 2.5 \text{ tons/year.}$$

Source: Derived from A. A. Webb (1974, Tables 22 and 23).

conveyance system sized for twice the existing peak flow is of adequate capacity to serve as a trunk system for residential development.

Because the Webb estimates were developed for sewers carrying only wash water, the larger system serves as a basis for this study in which all dairy wastes are transported. However, additional line capacity is assumed for prevention of clogging due to high solids content of slurried wastes. Rather than resizing the Webb system, it is assumed that a 10 percent increase over the "twice existing flow" total cost estimate compensates for the additional capacity. Thus, total cost of the sewer system is estimated to be \$11,974,875. Operation and maintenance (O & M) cost of the collection system totals \$12,000 per year. Assuming a 25 year life at 7 percent interest, annual costs equal \$1,027,444. Total annual cost including O & M is \$1,039,444.

Off-Dairy Waste System Cost Estimates

Cost estimates for the alternative off-dairy treatment processes and disposal methods are synthesized from published sources including Bechtel (1975), Black and Veatch (1971), Brown and Caldwell (1972), Culp, Wesner, and Culp (1974), A. A. Webb (1974), and private consultation with Professor George Tchbanoglous (1975).^{1/}

^{1/} Published treatment and disposal cost data are referenced principally to the Engineering News Record Construction Cost Index (ENRCC) and the Environmental Protection Agency-Sewage Treatment Plant Index (EPA STP). Reindexing of published data to a single common index and reference data is essential for comparability. For purposes of this study, all waste treatment and disposal system cost estimates are based on the ENRCC index of 2250, reflecting (footnote continued on next page)

Design parameter modifications, which alter process costs, were made when necessary to ensure compatibility with dairy wastes.^{1/}

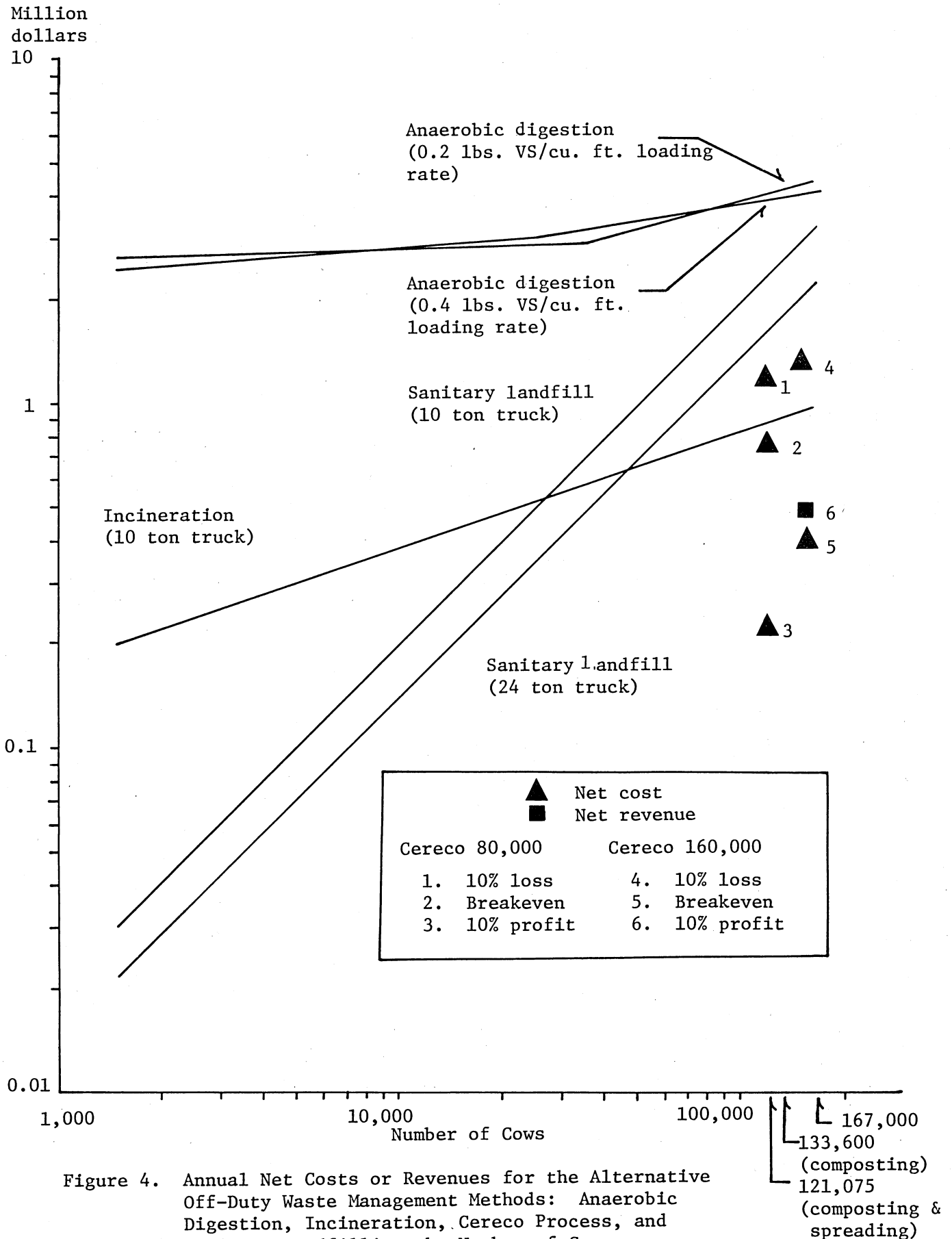
Annual process costs net of by-product recovery revenues are summarized in Figure 4. The cost estimates are related to a common capacity parameter--number of cows, and include all transportation, treatment, recovery, and disposal costs. Cost-capacity relationships for the Cereco Process are not estimated for the entire range of output. Rather, point estimates are computed under two capacity assumptions (one-half of all Basin manures are processed, and all Basin manures are processed), and three market conditions (break-even, 10 percent profit and 10 percent loss at plant capacity).^{2/} The economic benefit of managing wastes in a combination system is also shown in Figure 4. Limited alternatives to the various off-dairy systems involve composting 20 percent of Basin manures and spreading manure on dairy owned or controlled pasture. The three arrows along the abscissa at 167,000, 133,000, and 121,075 cows, represent capacity requirements for the various treatment and disposal alternatives assuming all manure is processed, 20 percent

(footnote 1 continued from previous page)

price levels in June 1975. The EPA-STP index changed in May 1975. An EPA-STP index of 240 was estimated to reflect price levels in June 1975. No attempt has been made to adjust this index to cost conditions peculiar to the Chino area. Moreover, no adjustments have been made to reflect price level changes through the project construction period.

^{1/} Details of the cost estimates are in Matulich (1976, pp. 107-116, 193-222).

^{2/} Point estimates are computed because no economies of size are attained beyond the 10,000 cow plant capacity. Thus, achievement of desired Basin-wide capacities requires modular construction. The two capacity assumptions correspond to alternate on-dairy management practices. In the absence of material recovery price or market data, alternative cost-revenue situations were considered to evaluate potential process performance.



is diverted to compost, and 20 percent is diverted to compost plus 7.25 percent is spread on pasture.

Essentially no off-dairy costs are incurred by the dairyman from composting and spreading. Unit costs are therefore reduced in the combination systems. A further unit cost reduction for the Cereco Process is attained by eliminating the under-utilized capacity in the last modular plant. Thus, minimum costs for the 80,000 cow unit are attained with the combination Cereco-disposal-composting-spreading system. Minimum costs/maximum revenues for the 160,000 cow unit are attained with the combination Cereco-spreading system.

The necessity of regional treatment and disposal methods is clearly demonstrated in Figure 4. Available scale economies are captured well beyond the largest dairy size. The regional framework, however, requires distributing off-dairy costs to the individual dairy as a user cost. These user costs (revenues) are presented in Table 15 on a per cow basis, and range from a net revenue of \$2.87 per cow to a net cost of \$26.53.^{1/}

General Dairy Costs

Dairy Equipment Costs

The difficulty of identifying efficient equipment combinations in agricultural operations is well known. Rarely is there an observable pattern of equipment complements within a particular farm size classification. Machinery combinations are developed for dairy

^{1/} User costs for the combination off-dairy and on-dairy systems are computed as the ratio of actual capacity to total cow population because composting and spreading incur no off-dairy costs.

Table 15: Ranking of Alternative Off-Dairy Waste Management Techniques by Total and Per Cow Net Annual Costs (-) or Revenues (+).

Process		Total net annual cost or revenue thousand dollars	Net annual per cow cost or revenue ^{a/} dollars
Cereco	160,000 (profit) ^{a/}	+ 480	+ 2.87
	80,000 (profit)	- 220	- 1.32
	160,000 (breakeven)	- 384	- 2.30
	80,000 (breakeven)	- 752	- 4.50
Incineration ^{b/}		- 875	- 5.24
Cereco	80,000 (loss)	-1,184	- 7.09
	160,000 (loss)	-1,248	- 7.47
Sanitary landfill (24 ton truck) ^{c/}		-2,200	-13.17
(10 ton truck)		-3,200	-19.16
Anaerobic digestion (0.4 loading rate)		-4,200	-25.15
(0.2 loading rate)		-4,430	-26.53

a/ The Cereco system refers to the combination Cereco-spreading system for the 160,000 cow capacity, and the combination Cereco-disposal-composting-spreading system for the 80,000 cow capacity.

b/ The incineration system refers to the combination incineration-composting-spreading system.

c/ Haul distance for the sanitary landfilling option is assumed to be 30 miles round trip.

related operations only, including equipment needed to perform routine tasks in the corral and alley area, feeding, and occasional pasture management.^{1/} Equipment requirements and costs for herd sizes less than 750 cows and between 750 and 1,200 cows are specified in Table 16. All machinery cost estimates are based on the retail price. Total machinery costs within a particular herd size equal the sum of General Equipment costs and Feeding Equipment costs. Since feeding equipment depends on the feed program, three feeding equipment options are specified. A bedding trailer is also required for free stall dairies.

Nonmilking Labor Costs

Dairy labor requirements generally follow an observable pattern by herd size. In this study we assume all labor is hired. There are two labor categories in addition to milker labor discussed earlier: herdsman and ranch hands. A herdsman performs essentially all of the managerial functions on the dairy and is responsible for day-to-day decisions regarding the dairy operation.^{2/} Ranch hands perform all necessary manual labor and assist the herdsman as needed. Supplemental part time or casual employees are occasionally hired.

^{1/} Routine corral operations do not include corral cleaning for dry lot housing. Rather, routine corral and alley operations refer primarily to occasional harrowing to promote drying and alley scraping. However, for free stall housing, both stall and adjacent corral cleaning are included.

^{2/} A herdsman is assumed to substitute for the owner-operator, especially common among the smaller dairies.

Table 16: General Dairy Equipment Costs, for Herds Less than 750 Cows and Between 750 and 1,200 Cows.

Less Than 750 Cow Herd Size			
	Purchase price	Life	Annual cost ^{a/}
	dollars	years	dollars
<u>General equipment</u>			
1 Tractor (40 hp. gasoline)	7,200	10	1,010
1 Front-end loader attachment	2,000	15	223
1 Blade attachment	700	15	78
1 Rotary mower (9')	2,000	10	280
1 Border disk (tandem)	900	15	101
1 Spring tooth harrow (8')	1,100	20	108
1 Pick-up (3/4 ton)	5,000	5	1,157
SUB TOTAL	19,800		2,957
1 Bedding trailer for free stalls	2,000	15	223
750 to 1,200 Cow Herd Size			
<u>General equipment</u>			
1 Tractor (40 hp. gasoline)	7,200	10	1,010
1 Tractor (60-70 hp. gasoline)	10,800	10	1,514
2 Front-end loader attachments	4,500	15	503
2 Blade attachments	1,400	15	156
1 Rotary mower (10')	2,200	10	308
1 Border disk (tandem)	900	15	101
1 Spring tooth harrow (12')	1,600	20	148
1 Pick-up truck (3/4 ton)	5,000	5	1,157
SUB TOTAL	33,700		4,897
1 Bedding trailer for free stalls	2,000	15	223

^{a/} Assumes a 10 percent salvage value and CFR corresponding to specified life; i.e., the CFR for 5 years = .2571, 10 years = .1558, 15 years = .1241, 20 years = .1095.

Source: Machinery Costs and Performance, Revised 4/75, A. D. Reed and L. A. Horel, University of California Cooperative Extension, Davis, California.

Labor requirements and costs are specified by herd size in Table 17.^{1/} Herdsmen's salaries vary by herd size, and for the purposes of this study are \$1,100 per month for the 375-499 cow range, \$1,350 per month for the 500-999 cow range, and \$1,500 per month for the 1,000-1,200 cow range. These figures are representative of average salaries paid in the Chino area for a "good" herdsman. However, salaries vary as much as \$200 per month dependent on qualifications. Ranch hand wages are derived from the Christian Labor Association Master Labor Agreement (CLA). The monthly wage rate for a six day week and a nine hour work day is \$800. Benefits for herdsmen and ranch hands are assumed to equal \$100 per month.^{2/} Employer FICA contributions are 5.85 percent of cash wages.

A fixed integer labor complement is valid for a fairly wide range of herd sizes, generating excess labor capacity at the lower extreme within a particular herd size range. Consequently, unit labor costs will decline as the fixed labor requirements are spread over greater numbers of cows. This capacity utilization problem is especially critical for the wide 500 to 999 cow range.

Utilization of a cow chaser to relieve milkers of chasing cows was discussed earlier. Because provision of cow chasers increases labor costs by an equivalent of two ranch hands (one per shift), an adjustment is necessary to compensate for excess ranch hand and cow

^{1/} Estimates in Table 17 do not include the additional cost of management and labor to feed cows under the dairy-mix feed program. The additional costs are deemed insignificant with respect to total annual dairy costs, and therefore, are ignored.

^{2/} Lack of information on herdsmen benefits motivates the assumption that both ranch hands and herdsmen receive equal benefits. The cost per employee is based on a \$25 and \$75 month contribution to the CLA Pension Trust, and Health and Welfare Trust Funds respectively.

Table 17: Monthly Nonmilking Labor Costs: With and Without Hired Chasers, by Milking Herd Size.

Without Hired Chaser					
Cash wages					
Herd size	Herdsman		Outside labor		Total wages
	number	dollars	number	dollars	dollars
375-499	1	1,100	0	--	1,100.00
500-999	1	1,350	1	800.72	2,150.72
1,000-1,200	1	1,500	2	1,601.44	3,101.44

With Hired Chaser						
Cash wages						
Herd size	Herdsman		Outside labor		Chasers	Total wages
	number	dollars	number	dollars	number	dollars
375-499	1	1,100	0	--	0	1,100.00
500-749	1	1,350	0	--	2	1,601.44
750-999	1	1,350	1	800.72	0	2,150.72
1,000-1,200	1	1,500	1	800.72	2	1,601.44
						3,902.16

Source: Derived from interviews with industry representatives.

chaser capacity. Chasers are assumed to replace one outside ranch hand in those herd sizes having excess capacity. Chasers are therefore employed in the 500-799 and 1,000-1,200 cow milking herd ranges. "Outside" labor costs including cow chasers, are summarized in the lower portion of Table 17.

Land Costs

Dairy owned land is minimal. County ordinances and the Santa Ana Regional Water Quality Control Board waste discharge orders establish the minimum land requirement at one acre per 40 cows. However, most of the dairies in the Chino area currently own double the required acreage. Consistent with present averages, this study assumes a land to cow ratio of one acre for every twenty cows.

Land values in the Chino basin range from \$5,000 to \$7,000 with an average of \$6,000 per acre assumed for the analysis. Land, unlike other durable factors considered in this study, is not subject to depreciation. Proximity to Los Angeles and increased urbanization are expected by many to cause substantial land appreciation in the Chino Basin. This appreciation has not, in fact, occurred. Land values have remained stable in recent years. In the absence of some basis to project future land values, land prices are assumed to remain constant. Therefore, land costs include only the cost of capital (interest charges at 9 percent) and taxes. Taxes on land are considered later as a component of personal property taxes.

Cow Costs

Total herd investment is based on a per cow cost of \$650. The annual cost of replacements are computed on the difference between

purchase price and cull price (\$375/cow). Given a use life of three years, the annual cost of replacement is approximately \$109 per cow for the total herd.

Miscellaneous Variable Costs

The two major variable costs of dairying (feed and labor) have been discussed. All other variable costs are lumped together under miscellaneous variable cost (MVC). Included in this category are: utilities, DHIA, veterinary and medicine, artificial insemination, maternity operations, calf care, dairy supplies, cow clipping and hoof trimming, gasoline, and repairs and maintenance. Each of these components, except gasoline and repairs and maintenance, are normally charged directly on a per cow basis. There is income from veal calf sales which is treated as an offset to MVC. Hence, it is expected that net MVC per cow is invariant with respect to herd size.

Miscellaneous variable cost estimates, excluding repairs and maintenance, are derived largely from Bureau of Milk Stabilization (BMS) Actual Cost Surveys. Miscellaneous variable costs per cow per year, less repairs and maintenance, are relatively constant at approximately \$72. The University of California Cooperative Extension Service, Riverside County, estimates annual repair and maintenance costs to be \$18 per cow.^{1/} Total MVC including repairs and maintenance is estimated to be \$90 per cow per year (\$72 + \$18).

^{1/} Because repair and maintenance costs vary with capacity utilization, estimating these costs on a per cow basis does not grossly misrepresent the actual functional relationship. /

Taxes and Insurance

Property taxes are assessed at the county level on land, buildings, equipment, other improvements, and cows. Because the Chino dairy production region encompasses parts of Riverside and San Bernardino Counties, the tax rate used in this study equals the respective county tax rates weighted by the relative cow population.^{1/} Combined land and personal property tax rates are \$11.00 per \$100 assessed value for San Bernardino County and \$9.80 per \$100 for Riverside County. The weighted average rate is approximately \$10.60 per \$100. Taxes on cows are subject to a 50 percent exemption. Average market value is assumed to be 100 percent of new cost for land and 66 percent for personal property.^{2/} The market value of cows is established on herd characteristics, recognizing the different values of first calf heifers through culls. In 1975 the market value of a cow was estimated at \$370 in San Bernardino County and \$380 in Riverside County. An average value of \$375 is chosen for this study.

Dairies in the Chino area commonly subscribe to liability and personal property insurance. According to an insurance representative, the rate for typical liability coverage (bodily injury and property damage) for Chino dairies is approximately \$.066 per \$100 of gross receipts. Given annual per cow milk production of 15,000

^{1/} The cow population is split approximately 65 percent in San Bernardino County and 35 percent in Riverside County.

^{2/} The 100 percent figure reflects the fact that market value of land is assumed constant over time. The personal property rate of 66 percent reflects depreciation over time. However, the average market value of personal property is greater than the half life value assumed by straight line depreciation which is selected for the purpose of recovering capital.

pounds, and milk price of \$9.00 per cwt., the annual premium is \$.891 per cow.^{1/}

Personal property insurance is primarily a function of market or replacement value. However, several factors including building construction, location, and accessibility are major determinants of insurance costs. Personal property insurance cost estimates are, therefore, generalized. The common rate used for Chino dairies was \$336 for the first \$45,000 of market value and \$8.00 per \$1,000 thereafter. The dry lot corrals are insured at a lower rate of \$6.00 per \$1,000. For purposes of this study a flat rate of \$7.00 per \$1,000 market value is assumed. As with computation of taxes, market value is estimated at 66 percent of new value.

Taxes and insurance costs corresponding to the various dairy configurations are presented in Appendix Tables B-1 through B-5.

Synthesis of Estimated Cost-Volume Relationships

Combining stage cost components for each specified dairy size yields an estimate of total annual costs for that dairy operated at capacity. Varying the rate of operation for each dairy yields a short-run total cost function. An envelope to these short-run cost functions provides an estimate of long-run costs as size of dairy varies.

Short-run cost functions are developed for single milking parlor dairy configurations ranging in size from 375 to 1,200 cows, and the corresponding long-run cost curve is derived. The long-run

^{1/} Because liability insurance is based on the "normal" annual gross receipts, the premium is determined by the base herd size. No adjustment is made for short-run variations in herd size.

cost curve is then extended to dairies with 3,600 cow capacity by considering multiple parlor configurations. A reader's guide to abbreviations used in this section is presented in Table 18.

Derivation of the Short-Run and Long-Run Cost Functions for Single Parlor Dairies

Combined Dairy Production-Waste Management Systems

Total annual costs corresponding to the least cost dairy configurations for alternative design capacity herd sizes and waste management methods are summarized in Table 19. One can make three general observations based on data in Table 19. First, comparison of total annual costs among alternative waste management systems for a given dairy indicates that incineration has the lowest costs followed by Cereco 80,000, sanitary landfilling, Cereco 160,000, and anaerobic digestion.^{1/} A second and related observation is that dry lot dairy configurations face lower costs of production than free stall configurations. Third, all but four of the least cost dairies have automated milking systems.

Estimated short-run costs are derived for dairies operated at 50 and 100 cows below capacity. Costs which can be reduced for below capacity operation include feed, miscellaneous variable costs (MVC), cow costs, milking labor, and variable waste management costs.^{2/} The fixed cost component will result in higher average costs for below capacity operations. Estimated short-run average costs for

^{1/} These findings are based on the optimistic "breakeven" price assumption for the Cereco 80,000 and 160,000 systems.

^{2/} Nonmilking labor is assumed constant throughout all short-run variations.

Table 18: A Readers Guide to Abbreviations.

Abbreviation	Definition
LRAC	Long Run Average Cost
SRAC	Short Run Average Cost
SRAC _i	Short Run Average Cost Curve for the i th design capacity herd size. For example, SRAC ₄₅₀ denotes the Short Run Average Cost Curve for the 450 cow herd size.
H _{5S}	Double 5 Herringbone parlor with swinging machines.
H _{10C}	Double 10 Herringbone parlor with conventional machines.
H _{10A}	Double 10 Herringbone parlor with automated machines.
H _{12A}	Double 12 Herringbone parlor with automated machines.
H _{16A}	Double 16 Herringbone parlor with automated machines.
SO ₃₋₂	Double 3 Side-Opening parlor with automated machines and a wash stall.
SO ₄₋₂	Double 4 Side-Opening parlor with automated machines and a wash stall.

Table 19: Total Annual Costs for Least Cost Dairies, by Herd Size, Parlor and Housing Configurations, and Waste Management Methods.

Herd size	Parlor	Housing size	Total Annual Cost				
			Dry lot			Free stall	
			Incineration	Sanitary landfill	Cereco 80,000	Cereco 160,000	Anaerobic digestion
		cows	-----thousand-----				
375	H _{5S}	100	399	402	401	412	419
400	H _{5S}	80	---	---	---	436	442
450	SO ₃₋₂	120	461	464	462	476	484
500	SO ₃₋₂	100	521	525	522	537	545
600	SO ₃₋₂	120	611	616	613	630	641
625	SO ₃₋₂	100	637	642	639	658	671
700	SO ₄₋₂	80	---	---	---	727	741
750	SO ₄₋₂	100	751	757	752	775	790
875	H _{10C}	100	975	982	977	1,001	1,019
900	H _{12A}	120	902	909	904	932	950
1,000 ^{a/}	H _{10A}	100	1,010	1,018	1,012	1,039	1,059
1,050 ^{a/}	H _{12A}	120	1,059	1,068	1,062	1,091	1,113
1,125 ^{a/}	H _{10C}	100	1,227	1,236	1,230	1,263	1,286
1,200 ^{a/}	H _{16A}	120	1,199	1,208	1,201	1,234	1,259

^{a/} With hired chasers.

the various dairy sizes operated at capacity, 50 cows below capacity, and 100 cows below capacity are shown in Table 20.

Note that the estimated cost adjustments for below capacity operation do not explicitly distinguish between variations in herd size due to milking or dry cows but rather assumes that the proportion of milking cows remains at 80 percent.^{1/}

Short-run average cost (SRAC) curves for the five combined dairy production and waste management systems based on data in Table 20 are illustrated in Figure 5. The shape of the SRAC curves is consistent with the theoretical expectation that costs decline at a decreasing rate. The cost advantages of operating at capacity are illustrated in Figure 5.

The long-run average cost (LRAC) curve, sometimes referred to as the planning curve, for single parlor dairies is defined by an envelope to the short-run average cost curves for the dry lot/incineration system (Figure 5). The function is discontinuous and provides evidence of significant economies of size. Unit costs decline rapidly up to the 450 cow herd size and continue to decrease to the 750 cow herd size, where most cost advantages associated with size are realized. As shown in Table 20 and Figure 5, unit

^{1/} The study specification that a herd is comprised of 20 percent dry and 80 percent milking cows has an important consequence on the level of average costs. The particular percentages reflect the number of days per year a cow is lactating or dry. The greater percentage of time a cow is lactating, the higher the average cost. In particular, average feed costs per cow are higher for a longer lactation cycle because the cows are fed a high energy ration a greater proportion of the year. Consider, for example, a change from 80%/20% (292 day lactation) to 83.5%/16.5% (305 day lactation). Feed costs would rise \$.032 per cow per day, or equivalently, \$11.68 per cow per year. Average costs in general would also rise as fixed costs are spread over smaller herd sizes (e.g., the 1,200 cow herd reduces to 1,150 cows, comprised of 960 lactating and 190 dry cows). Some of the cost increments, however, would be offset as other variable costs decline with the smaller herd sizes.

Table 20: Short-Run Average Costs for Least Cost Dairies, by Herd Size, Housing Classification, and Waste Management System.

Herd size	Parlor	Housing size	Dry lot								
			Incineration			Sanitary landfill			Cereco 80,000		
			Capacity	-50	-100	Capacity	-50	-100	Capacity	-50	-100
cows			-----dollars per cow-----								
375	H _{5S}	100	1,065	1,093	1,132	1,073	1,101	1,140	1,068	1,097	1,137
400	H _{5S}	80	---	---	---	---	---	---	---	---	---
450	SO ₃₋₂	120	1,024	1,045	1,072	1,032	1,053	1,080	1,026	1,048	1,076
500	SO ₃₋₂	100	1,041	1,062	1,088	1,049	1,070	1,096	1,043	1,065	1,091
600	SO ₃₋₂	120	1,019	1,035	1,053	1,027	1,043	1,061	1,021	1,037	1,056
625	SO ₃₋₂	100	1,019	1,033	1,050	1,027	1,041	1,058	1,022	1,036	1,053
700	SO ₄₋₂	80	---	---	---	---	---	---	---	---	---
750	SO ₄₋₂	100	1,001	1,012	1,024	1,009	1,020	1,032	1,003	1,014	1,027
875	H _{10C}	100	1,114	1,128	1,145	1,122	1,136	1,153	1,116	1,131	1,148
900	H _{12A}	120	1,002	1,011	1,021	1,010	1,019	1,029	1,004	1,013	1,024
1,000 ^{a/}	H _{10A}	100	1,010	1,017	1,027	1,018	1,025	1,035	1,012	1,019	1,030
1,050 ^{a/}	H _{12A}	120	1,009	1,016	1,025	1,017	1,024	1,033	1,011	1,018	1,028
1,125 ^{a/}	H _{10C}	100	1,091	1,102	1,114	1,099	1,110	1,122	1,093	1,105	1,117
1,200 ^{a/}	H _{16A}	120	999	1,005	1,012	1,007	1,013	1,020	1,001	1,007	1,014

(continued)

Table 20 (continued)

			Free stall					
Herd size	Parlor	Housing size	Cereco 160,000			Anaerobic digestion		
			Capacity	-50	-100	Capacity	-50	-100
cows			-----dollars per cow-----					
375	H _{5S}	100	1,098	1,132	1,179	1,116	1,150	1,196
400	H _{5S}	80	1,089	1,122	1,164	1,106	1,137	1,178
450	SO ₃₋₂	120	1,057	1,084	1,117	1,076	1,102	1,136
500	SO ₃₋₂	100	1,073	1,097	1,129	1,090	1,115	1,146
600	SO ₃₋₂	120	1,050	1,069	1,092	1,069	1,087	1,109
625	SO ₃₋₂	100	1,053	1,071	1,091	1,073	1,091	1,111
700	SO ₄₋₂	80	1,039	1,054	1,071	1,059	1,073	1,090
750	SO ₄₋₂	100	1,033	1,047	1,062	1,053	1,067	1,082
875	H _{10C}	100	1,144	1,161	1,180	1,164	1,082	1,200
900	H _{12A}	120	1,035	1,046	1,058	1,055	1,066	1,078
1,000 ^{a/}	H _{10A}	100	1,039	1,049	1,060	1,059	1,069	1,081
1,050 ^{a/}	H _{12A}	120	1,039	1,049	1,060	1,060	1,069	1,080
1,125 ^{a/}	H _{10C}	100	1,123	1,135	1,148	1,143	1,156	1,169
1,200 ^{a/}	H _{16A}	120	1,028	1,036	1,044	1,049	1,057	1,065

^{a/} With hired chasers.

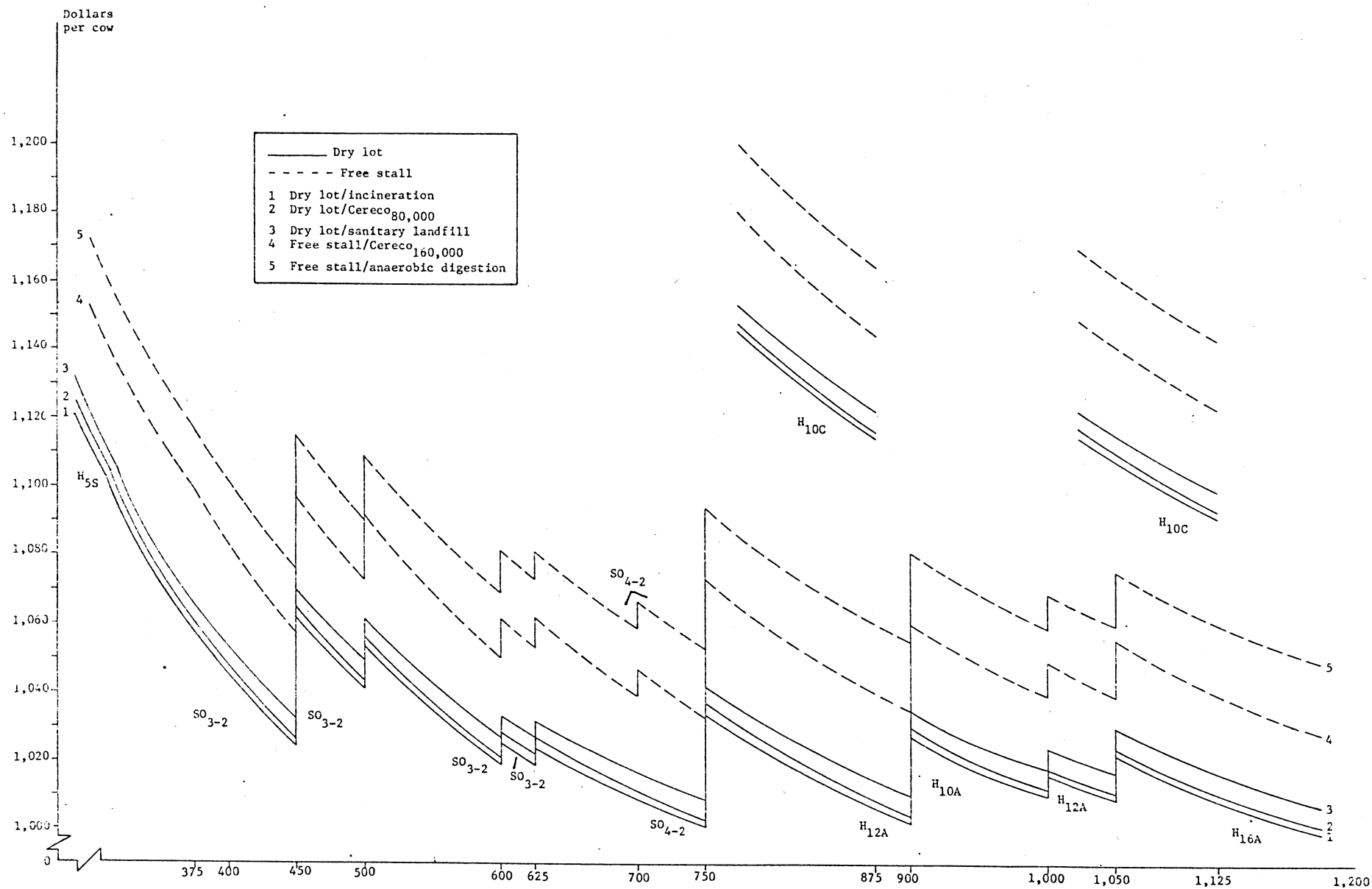


Figure 5. Short- and Long-Run Average Cost Curves for Five Combined Dairy Production and Waste Management Systems: Single Parlor Configurations from 375 to 1,200 Cow Design Capacities.

costs for 750, 900, and 1,200 cow dairies are approximately equal at \$1,001, \$1,002, and \$999 per cow respectively.^{1/}

These results are striking when compared with previous studies of economies of size in dairying. Economies of size are available for herd sizes five times greater than previously found. Consideration of new semi-automated milking parlors is primarily responsible for this conclusion. The largest portion of economies are realized at 450 cows--the first herd size to employ a semi-automated milking system. Over 60 percent of the reduction in unit costs are attained between the nonautomated 375 cow dairy configuration and the automated 450 cow dairy. Further reductions in unit costs to the 750 cow size are available from better capacity utilization of the milking parlor and alternative milking techniques.

Careful examination of the LRAC curve throughout its range suggests several important implications. The first major implication is observed at the shift from the labor intensive H_{5S} milking system to the capital intensive automated SO_{3-2} milking system. Substitution of capital for labor is responsible for the 450 cow herd short-run average cost curve ($SRAC_{450}$) lying below $SRAC_{375}$. Curves drawn in Figure 5, however, disregard the minimum milking time constraint imposed by the labor union.^{2/} In actuality, upon reaching the 6 hour limit, $SRAC_{450}$ changes in one of two fashions: $SRAC_{450}$ either rises sharply because the milker wage remains constant

1/ Marketing costs including licenses, association fees, and milk hauling charges, were omitted from this analysis. According to the Bureau of Milk Stabilization, marketing costs total approximately \$50 per cow, and their inclusion would shift the LRAC up by that amount.

2/ Recall that the minimum milking time per man is 6 hours per day. This restriction was imposed in the context of this study only to determine the initial parlor to capacity herd size correspondence.

for subsequent herd size decrements, or else is discontinuous, following along the SRAC trace of the next best parlor configuration. In the absence of a minimum time restriction, the relation depicted in Figure 5 is valid.

The second implication is apparent as capacity increases from 450 cows to 500 cows: unit costs rise from \$1,024 to \$1,041 per cow even though the same milking technique is employed. While discontinuities result ostensibly from changes in milking techniques and increments of housing units, the discontinuity from 450 to 500 cows is based almost exclusively on labor. Recall that a particular outside labor complement is valid for a fairly wide range of herd sizes. At 500 cows a different, higher cost labor complement is required.

Unit costs decline beyond 500 cows up to the 750 cow SO_{4-2} dairy. Beyond 750 cows, unit costs rise slightly and then decline. Expansion beyond 900 cows requires adoption of cow chasers. In response to the change in outside labor requirements, unit costs lie above the minimum long-run average cost for $SRAC_{1000}$ and $SRAC_{1050}$, returning to the minimum level at the 1,200 cow herd size as the additional labor costs are spread over more cows.

We have included $SRAC_{875}$ and $SRAC_{1125}$ in Figure 5 even though they are clearly irrelevant in determining the LRAC curve because the H_{100} dairy configuration is fairly common in the Chino area. Hence, $SRAC_{875}$ and $SRAC_{1125}$ illustrate the common deviation from the efficiency frontier of existing dairies operating under the most favorable conditions. The data indicate that it is possible to reduce costs from \$70 to \$100 per cow with the installation of labor

saving semi-automatic milking equipment.^{1/} With cost reductions of this magnitude possible, we expect comparatively rapid adoption of automated milking parlors in the study area.

Dairy Production Costs Excluding Waste Management

The impact of waste management on dairy production costs can be examined by calculating costs for least cost dairies excluding waste management. We specify total annual dairy costs exclusive of waste management for each technically feasible parlor configuration for both dry lot and free stall housing.^{2/} Short-run average total costs corresponding to the least cost alternative for each dairy size are presented in Table 21. The associated SRAC curves are illustrated in Figure 6.

A comparison of costs in Table 21 shows that dry lot housing yields \$25 to \$30 lower unit production costs than does free stall housing for all herd sizes. This difference in housing costs has a significant impact on the integrated waste management system selected as the least cost alternative. Housing design is the major determinant of the applicability of a particular treatment and/or disposal method. If waste treatment and disposal costs are minimized and the resultant methods simply tacked-on to the dairy, a sub-optimal overall system (based on the user cost ranking) would be

^{1/} Note that the SRAC₈₇₅ and SRAC₁₁₂₅ curves are based on optimal feeding programs, which are not widely practiced. As drawn, these curves are more than \$50 per cow lower than with the existing feed programs.

^{2/} Estimates total annual costs for each dairy configuration excluding costs of waste treatment and disposal are included in Appendix D.

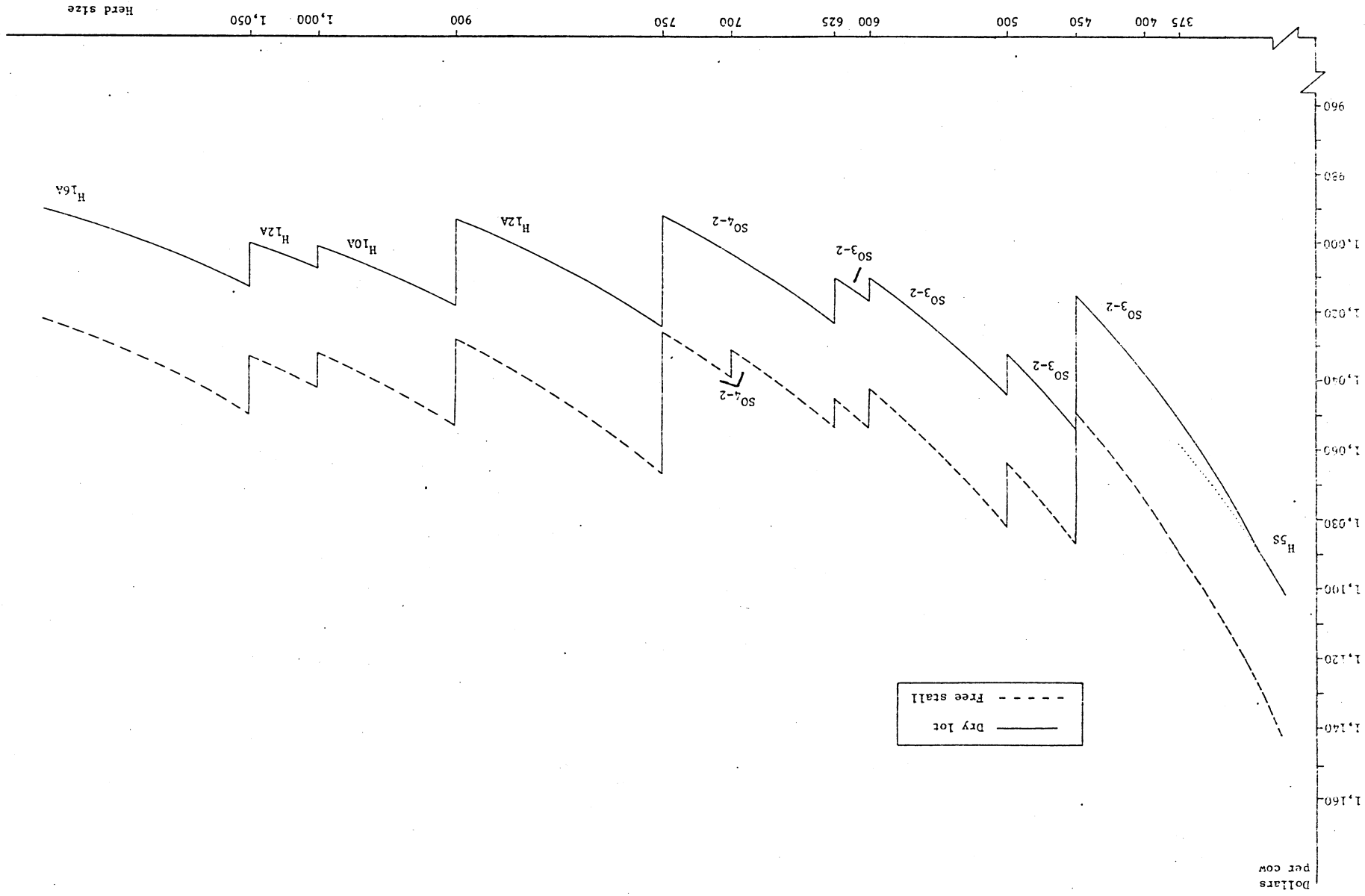
Table 21: Short Run Average Costs for Least Cost Dairies Excluding Waste Management, by Herd Size, Variable Cost Adjustment Per Cow, and Housing Configurations.

Herd size	Variable cost adjustment per cow a/	Free Stall Housing				Dry Lot Housing			
		Total annual cost at capacity	Average annual cost			Total annual cost at capacity	Average annual cost		
			Capacity	Less 50 cows	Less 100 cows		Capacity	Less 50 cows	Less 100 cows
	dollars	dollars	dollars per cow			dollars	dollars per cow		
375	871	408,000	1,089	1,122	1,168	395,969	1,056	1,084	1,123
400	860	431,000	1,078	1,109	1,150	---	---	---	---
450	845	472,000	1,049	1,075	1,108	456,561	1,015	1,036	1,063
500	845	532,000	1,063	1,087	1,118	516,056	1,032	1,053	1,079
600	845	625,000	1,042	1,060	1,082	606,389	1,010	1,026	1,044
625	845	653,000	1,045	1,063	1,083	631,148	1,010	1,024	1,041
700	845	722,000	1,031	1,045	1,062	---	---	---	---
750	845	770,000	1,026	1,039	1,054	744,442	992	1,003	1,015
875	860	995,000	1,137	1,154	1,172	966,521	1,105	1,119	1,136
900	845	925,000	1,028	1,039	1,051	894,145	993	1,002	1,012
1,000	845	1,032,000	1,032	1,042	1,053	1,000,700	1,001	1,008	1,018
1,050	845	1,084,000	1,033	1,042	1,053	1,049,634	1,000	1,007	1,016
1,125	860	1,256,000	1,116	1,128	1,141	1,217,345	1,082	1,093	1,105
1,200	845	1,226,000	1,022	1,030	1,038	1,187,762	990	996	1,003

a/ Variable cost adjustment per cow equals (cost of feed + miscellaneous variable costs + cow costs + milking labor adjustment) x (.8).

Source: Appendix D.

Figure 6. An Aggregation of Short-Run Average Cost Curves for Single Parlor Dairy Configurations Without Waste Management Costs, By Housing Type.



obtained. By simply minimizing cost of treatment and disposal, Cereco 160,000 is least cost, followed by Cereco 80,000, incineration, sanitary landfilling, and anaerobic digestion. Under the integrated dairy production system, however, the Cereco 160,000 system moves from first to fourth ranked, the Cereco 80,000 system remains second ranked, incineration moves from third to first ranked, sanitary landfilling moves up a position to third ranked, and anaerobic digestion remains unchanged in the fifth ranked position.^{1/}

Feed and Nonfeed Costs

Further examination of dairy costs is performed by separating feed and nonfeed cost components. Feed prices are volatile and feed is the single most important component of annual production costs. A change in the ration cost will change the position of the average cost curves but will not change their shape since feed cost per cow does not vary with the size of the dairy.

In this study feed costs were estimated at \$635 per cow. Non-feed dairy production costs are derived by subtracting \$635 per cow from the figures in Table 21. The resulting costs are presented in Table 22. A comparison of data in Tables 21 and 22 indicates that feed accounts for 60 to 65 percent of annual average production costs.

^{1/} This least cost integrated dairy/waste management system ranking is predicted upon the "breakeven" price assumption for the Cereco Process. The alternative price assumptions of a 10 percent profit or a 10 percent loss were found to leave the relative ranking essential unchanged. See Matulich (1976, pp. 107-117).

Table 22: Short-Run Average Costs for Least Cost Dairies Excluding Waste Management and Feed, by Herd Size and Housing Configuration.

Herd size	Free Stall Housing				Dry Lot Housing			
	Total annual cost at capacity	Average Annual Cost			Total annual cost at capacity	Average Annual Cost		
		Capacity	-50	-100		Capacity	-50	-100
	dollars	---dollars per cow---			dollars	---dollars per cow---		
375	170,099	454	487	533	157,844	421	449	488
400	177,056	443	474	515	--	-	-	-
450	186,377	414	440	473	170,811	380	401	428
500	214,087	428	452	483	198,556	393	418	444
600	244,414	407	425	447	225,389	375	391	409
625	256,367	410	428	448	234,273	375	389	406
700	277,306	396	410	419	--	-	-	-
750	293,449	391	404	419	268,192	357	368	380
875	439,127	502	519	537	410,896	470	484	501
900	353,632	393	404	416	322,645	358	367	744
1,000	396,977	397	407	418	395,700	366	373	383
1,050	417,689	398	407	418	382,884	365	372	381
1,125	541,195	481	493	506	502,970	447	458	470
1,200	464,221	387	395	403	425,117	355	361	368

Source: Derived from Table 21.

Estimated Long-Run Average Costs for Single and Multiple Parlor Dairies

The costs just calculated are for dairies ranging in size from 375 to 1,200 cows. Several dairies in the Chino area, however, are larger than 1,200 cows; the largest has approximately 3,600 cows. Costs for these large multiple parlor dairies can be estimated by combining two or more single parlor dairies. We examine costs for dairy sizes in the range of 375 to 3,600 cows.

Large multiple parlor dairies are typically organized with adjacent milking parlors at the head of housing facilities. Excess capacity in certain productive factors in single parlor dairies affords potentially lower unit costs through more complete capacity utilization in the multiple parlor dairies. Consolidation of certain production activities among the combined dairies by substituting larger, more efficient technology (i.e., technologies with a more favorable cost-volume relations) offers an opportunity to further lower production costs.

Four productive factors potentially allow for better capacity utilization and consolidation: general dairy equipment, refrigeration equipment, cow chasers, and management (herdsman).

- General dairy and feeding equipment complements (Tables 12 and 16) are fixed for a fairly wide range of herd sizes, yielding excess capacity at the lower ends of those ranges. Moreover, much of the equipment remains idle during a portion of the day offering a potential for consolidation. Thus, the equipment complement for combined dairies need not be organized as two complete sets. Rather, the equipment could be organized as a single large set that includes

certain additional key components, e.g., an additional tractor, pick-up truck, and feeding equipment.

- Refrigeration equipment (within the ice builder and plate cooler classification) offers substantial economies of size with opportunity for capacity expansion beyond the size range presented in Table 8. Because of the high cooling efficiency, adjacent parlors may utilize a single refrigeration system without a comparable increase in refrigeration capacity.
- Hired cow chasers under single parlor configurations experience excess capacity in the form of lead-time when changing tasks (about 10 minutes per string). Multiple parlor dairy configurations could permit chasers to specialize, thereby eliminating lead-time.
- Management is often argued as the major impediment to capacity expansion. Three alternatives are available to avoid this impediment. First, each sub-dairy may be managed by its own separate manager. But this organization induces coordination problems and offers no cost reduction advantage. Second, a better quality manager may be employed. Based on observation, however, the maximum herd size a single manager can effectively administer is limited to not much more than 1,200 cows. The final alternative is to have an additional layer of management which would promote specialization of managerial skills. Larger dairies could be effectively managed at slightly lower unit costs under this organization.

Efficient combined dairy configurations beyond 1,200 cows are determined by minimizing joint costs. From the 1,200 to 3,600 cow range, there are 15 different design capacities formed as combinations of the 750, 900, and 1,200 cow least cost, single parlor configurations--each with approximately equivalent unit costs.^{1/} The smallest least cost, design capacity multiple parlor configuration is a replication of the 750 cow-SO₄₋₂ dairy configuration--300 cows larger than the largest single parlor configuration. Equivalent unit costs are available at 150 cow increments between the various multiple parlor configurations within the 1,500 and 3,600 cow range. Deviations above minimum average costs would be small between any two of these design capacity configurations. The large number of potential dairy combinations coupled with minimizing joint costs, compresses the discontinuities found in single parlor dairies. Hence, reasonable continuity would be achieved beyond the 1,200 cow herd size.

Because most annual dairy costs (85-90 percent) are continuously variable, potential cost reductions from fuller capacity utilization and consolidation are small. Detailed cost estimates for the multiple parlor dairies were not made. Rather, we examined the potential cost advantages stemming from full utilization of factors with excess capacity. The average total annual cost for the 1,200 cow dairy operated at capacity under specifications of this study was \$999. We

1/ For example, the least cost 2,700 cow capacity dairy may be formed by combining two 750 cow-SO₄₋₂ configurations plus one 1,200 cow-H_{16A} configuration, or three 900 cow-H_{12A} configurations. It should be noted, however, that given equivalent unit costs, a dairyman should opt to replicate a single parlor configuration rather than a combination of parlor configurations. Like operations and equipment are easier to manage and maintain.

estimate that the maximum advantage for the 3,600 dairy would be \$5 per cow for an average total annual cost of \$994.

Dairy Planning Functions

The results of this study can be summarized in a long-run average cost curve or planning function. To estimate this function, which is an envelope to the short-run cost functions, we ignore the discontinuities shown in Figure 5. Costs for single parlor dairies with a capacity of 375, 450, 600, 750, and 1,200 cows were combined with costs for multiple parlor dairies to estimate the planning function. We estimate functions for dairying with waste management, dairying excluding waste management, and nonfeed dairy costs.

The planning function was estimated by fitting an envelope curve to the total cost observations.^{1/} Both linear and curvilinear forms were estimated, with the linear form providing the best estimate of the data.

The estimated total annual cost of dairying including costs of waste management for Chino dairies in the 375 to 3,600 cow range is:

$$TC_w = 6,631.58 + 992.16 Q$$

where TC_w is total cost including waste management Q is capacity size of dairy.^{2/}

This yields the estimated planning function:

$$ATC_w = 6,631.58/Q + 992.16$$

^{1/} We used a linear programming algorithm developed by Daryl Carlson (1976) to estimate the envelope functions. The algorithm minimizes the sum of the positive residuals.

^{2/} The comparable equation estimated using ordinary least squares (O.L.S.) methods is:

$$TC_w = 16,860.20 + 989.09 Q.$$

where ATC_w is the long-run average total cost of dairying including waste management.

The estimated total cost of dairying excluding the costs of waste management (TC_D) is:^{1/}

$$TC_D = 6,631.58 + 983.16 Q$$

which yields the planning function:

$$ATC_D = 6,631.58/Q + 983.16.$$

This function is \$9 below ATC_w at each dairy size.

The estimated total cost function for nonfeed dairy costs (TC_{NF}) is:^{2/}

$$TC_{NF} = 6,631.58 + 348.16 Q$$

which yields the average total cost of nonfeed dairy costs of:

$$ATC_{NF} = 6,631.58/Q + 348.16.$$

The estimated planning functions demonstrate little cost advantage for very large scale (3,600 cows) dairy operations. As shown by the short-run average cost data (Table 20), most of the available economies of size can be attained by a 750 cow dairy. The estimated envelope functions do not illustrate the significant cost reduction available in the 375 to 750 cow size range. Observations for the 375 and 450 cow dairies have the largest residuals. This is due to the large range of observations (375 to 3,600 cows)

1/ The O.L.S. estimate of the function is:

$$TC_D = 16,810.60 + 979.79 Q.$$

2/ The O.L.S. estimate of the function is:

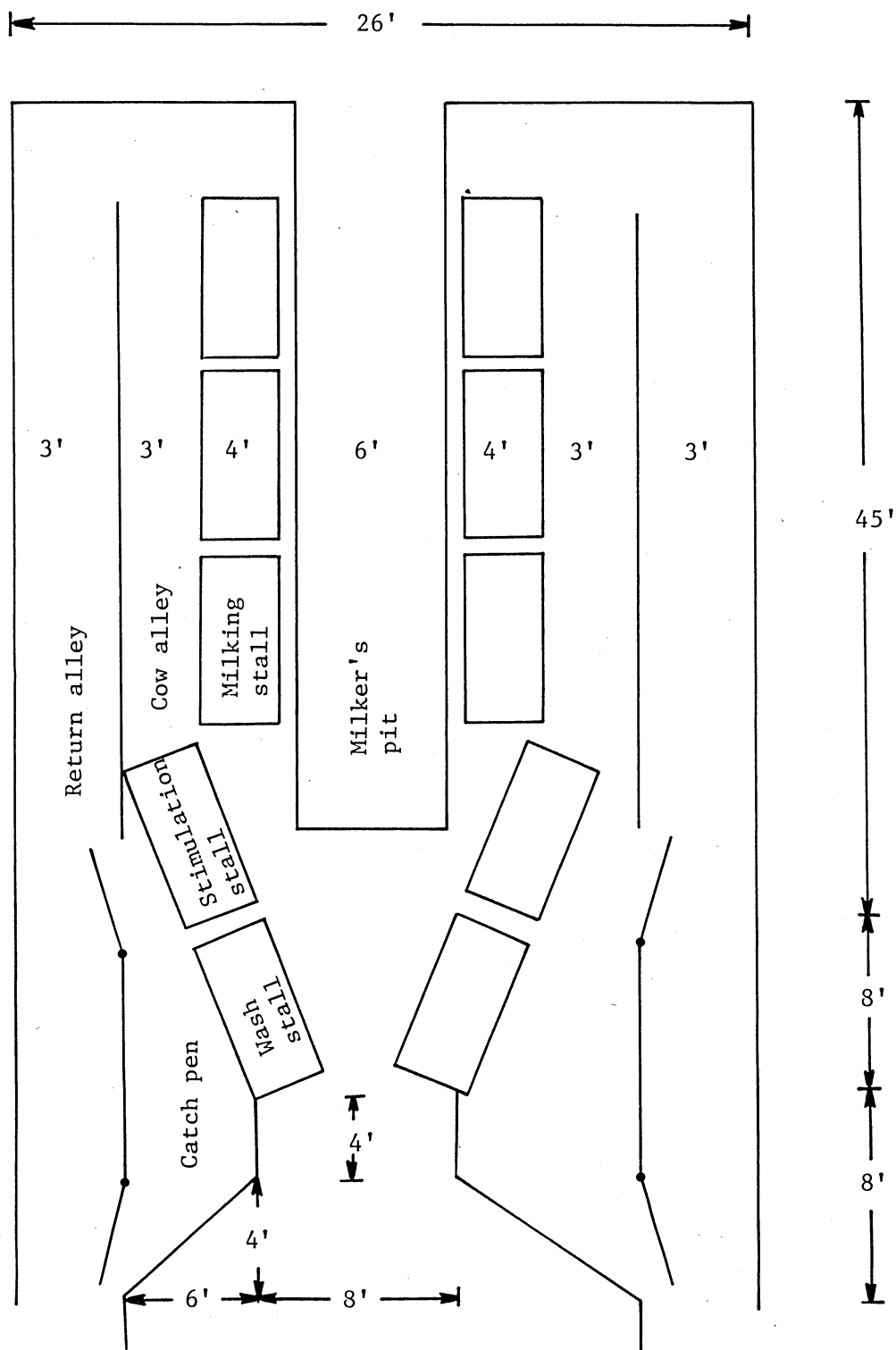
$$TC_{NF} = 16,810.60 + 344.79 Q.$$

and the algorithm used. Restriction of the range of observations to 1,200 cows or fewer will result in a larger fixed cost coefficient in the estimated total cost equations. The estimated average total cost including waste management for a 375 cow dairy is \$1,065; for a 750 cow dairy it is \$1,001; for a 1,200 cow dairy it is \$999; and, for a 3,600 cow dairy it is \$994.

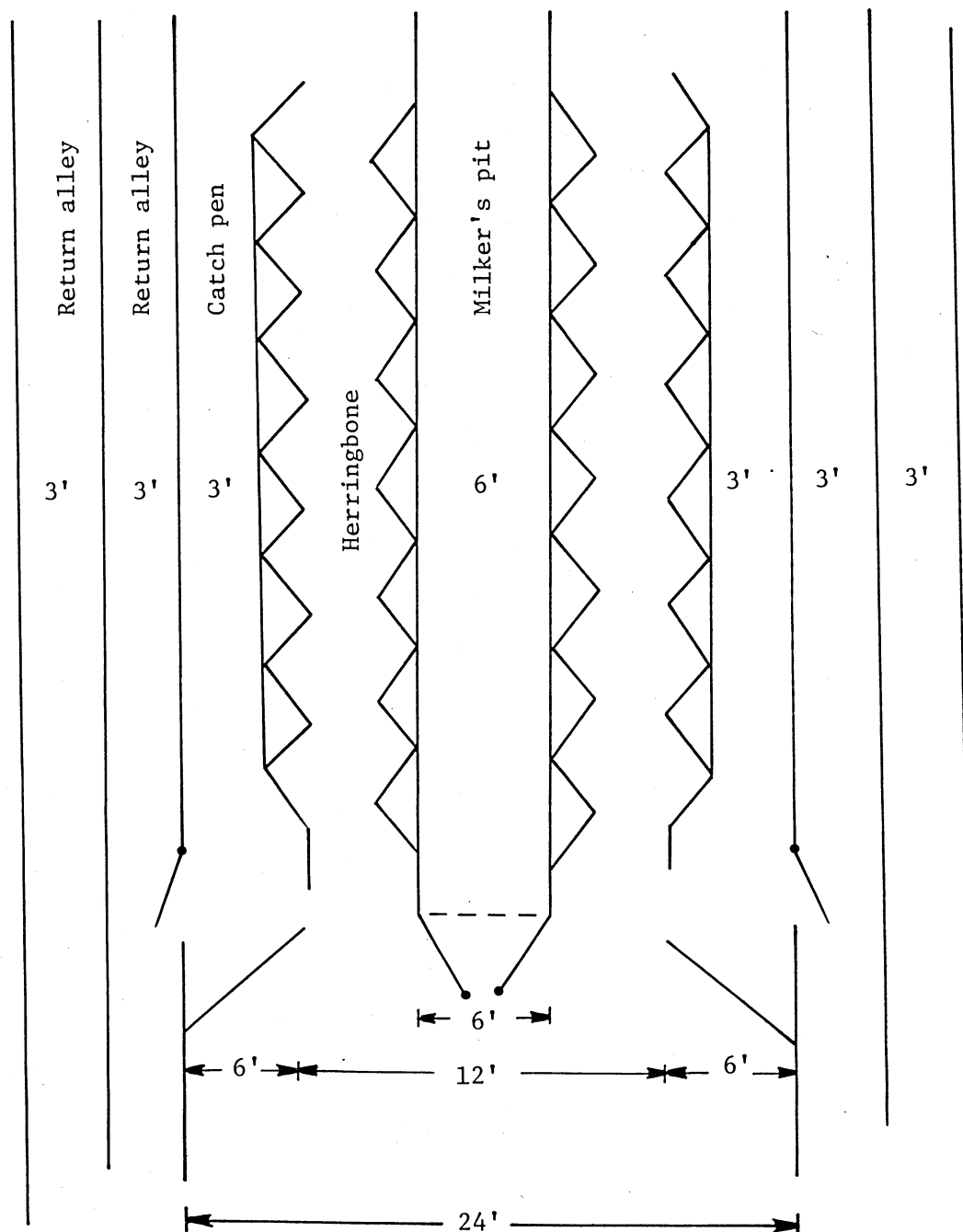
APPENDIX A

FIGURES A-1 THROUGH A-7 AND TABLES A-1 THROUGH A-10

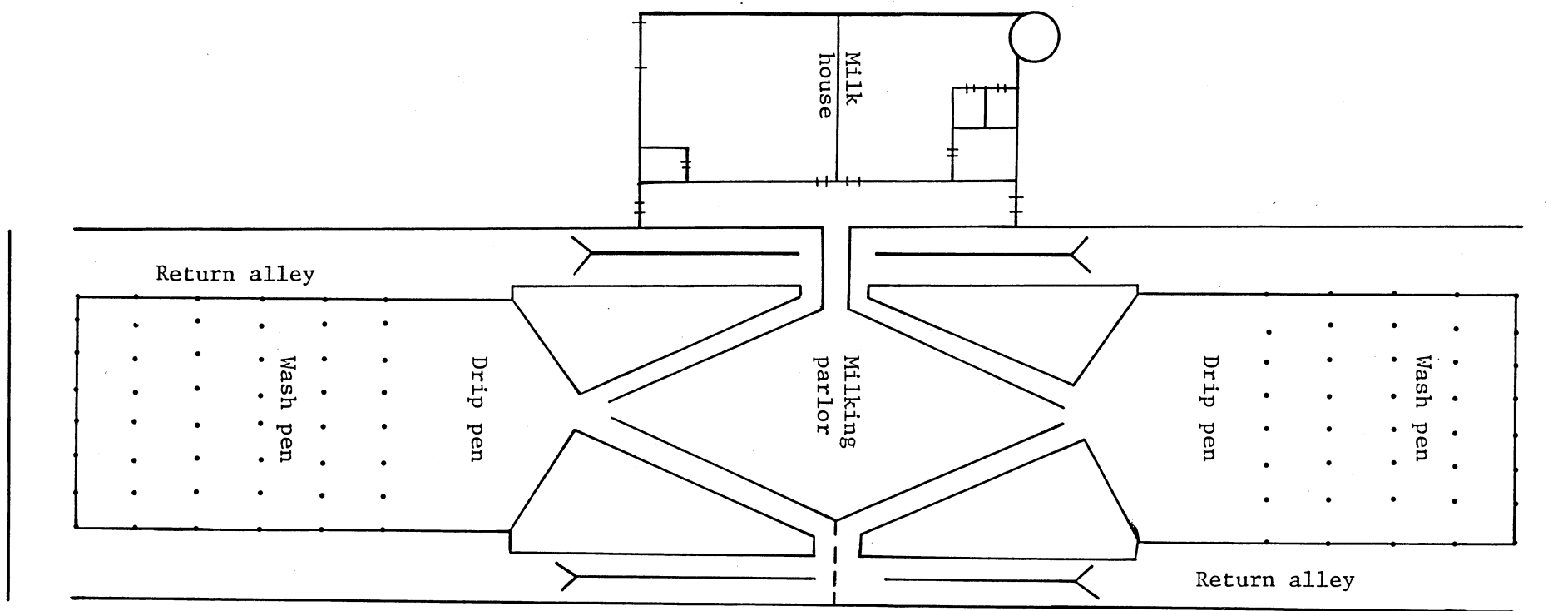
Derivation of Component Construction Costs



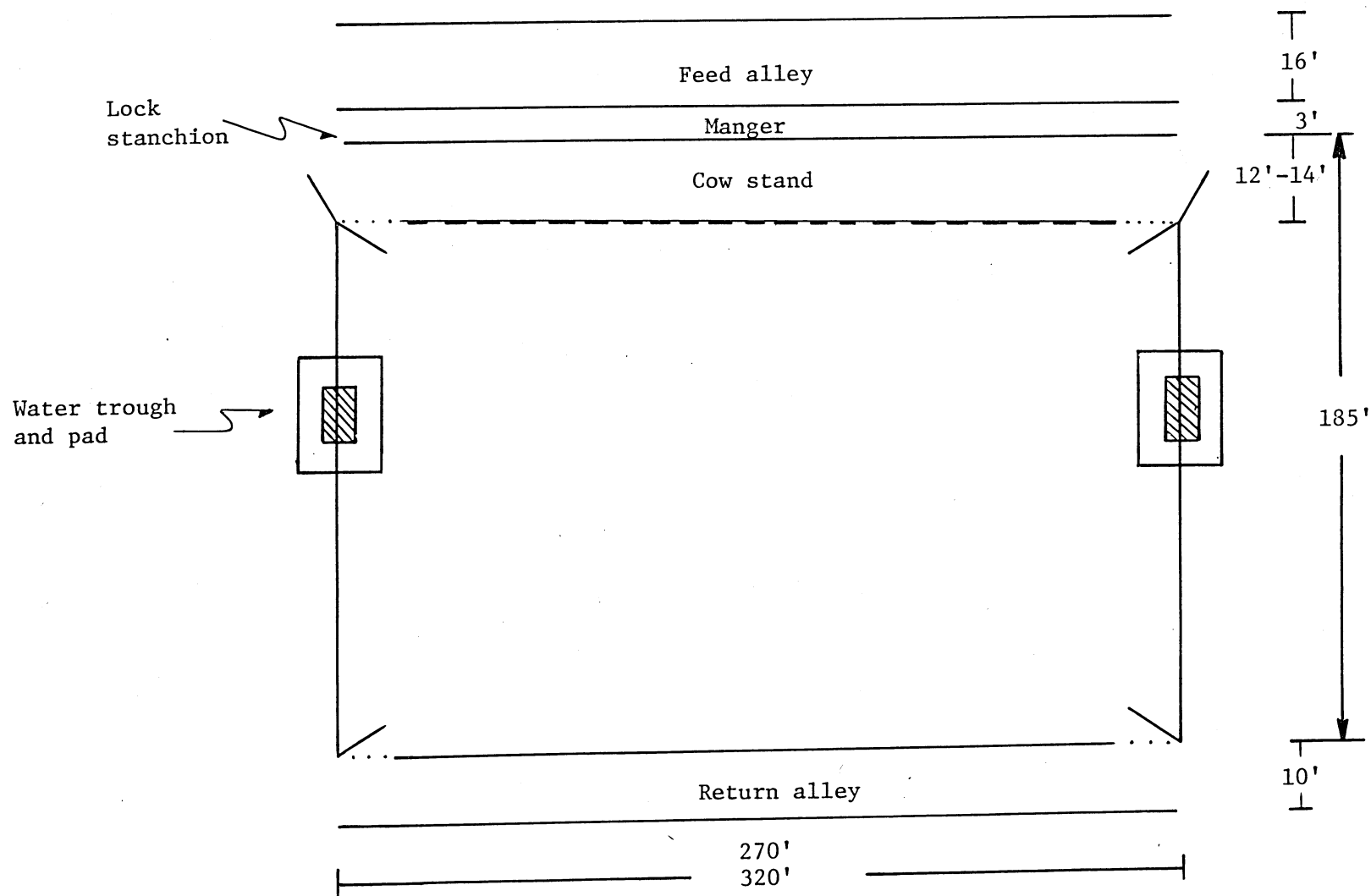
Appendix Figure A-1. Illustration of a Side-Opening Milking Parlor



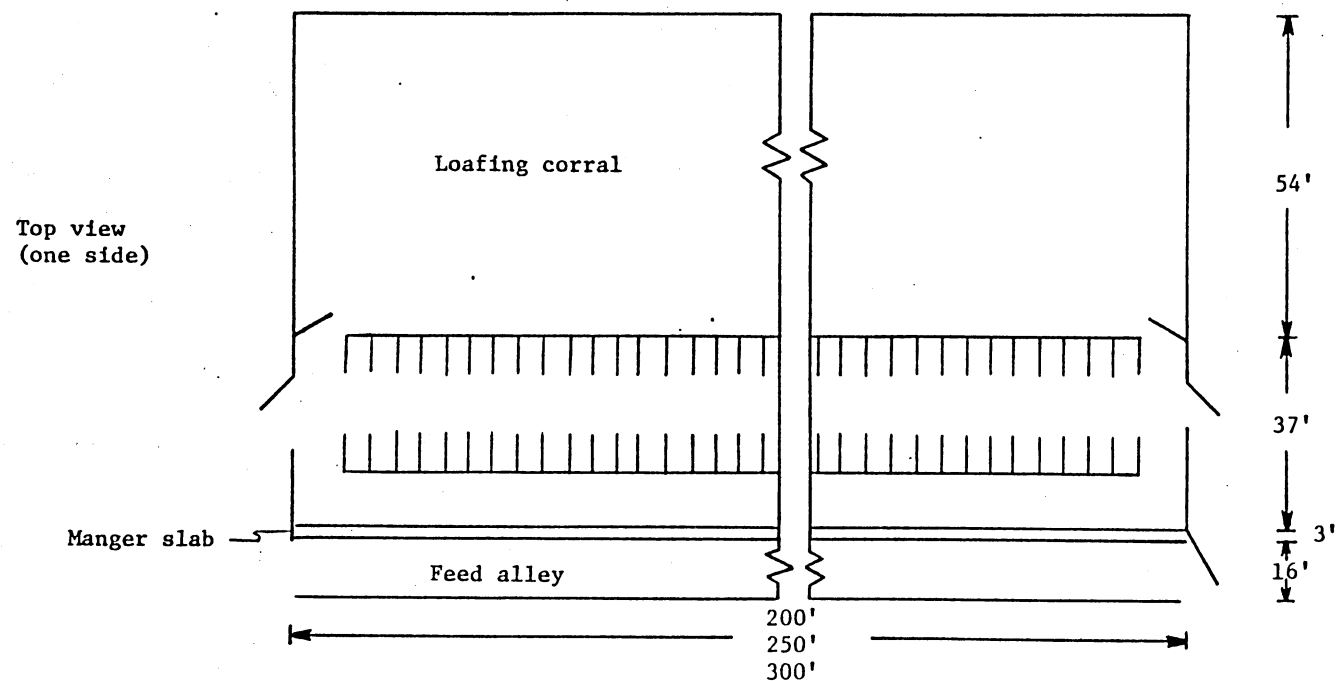
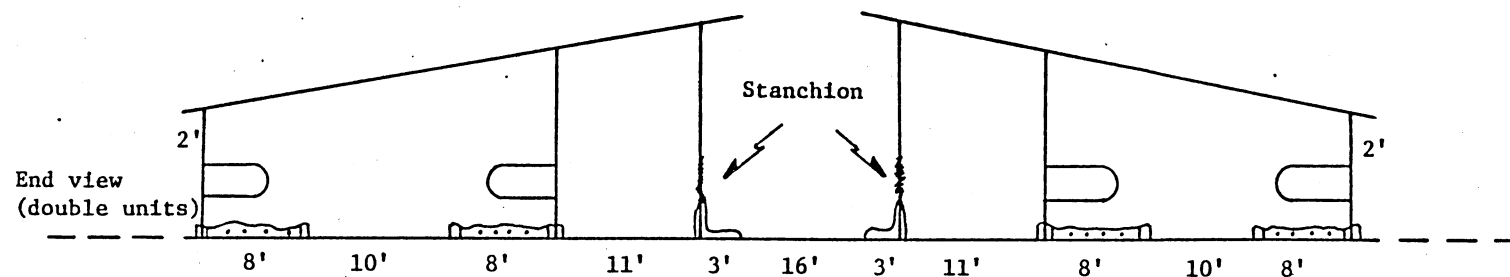
Appendix Figure A-2. Illustration of a Herringbone Milking Parlor



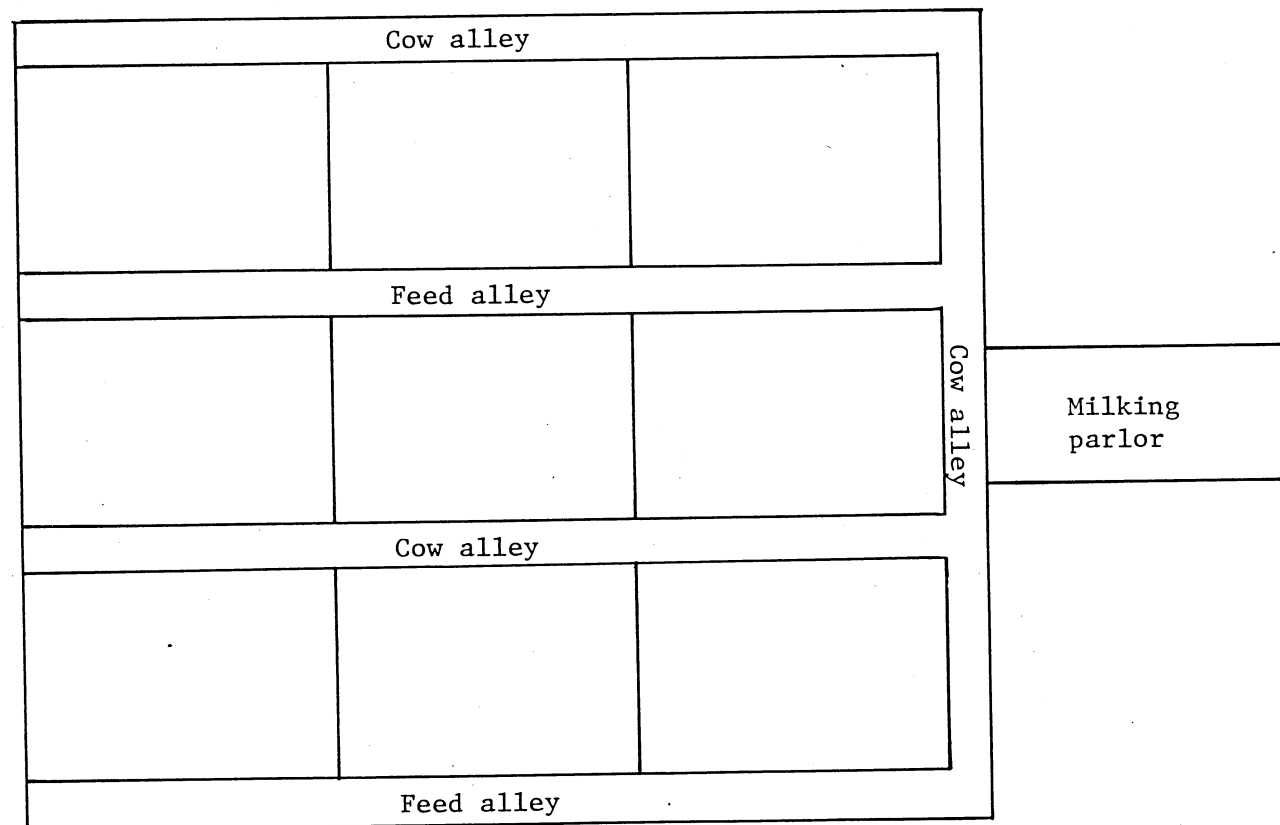
Appendix Figure A-3. Illustration of a Polygon Milking Parlor with Drip Pen, Wash Pen, and Milk House
(all dimensions vary with capacity)



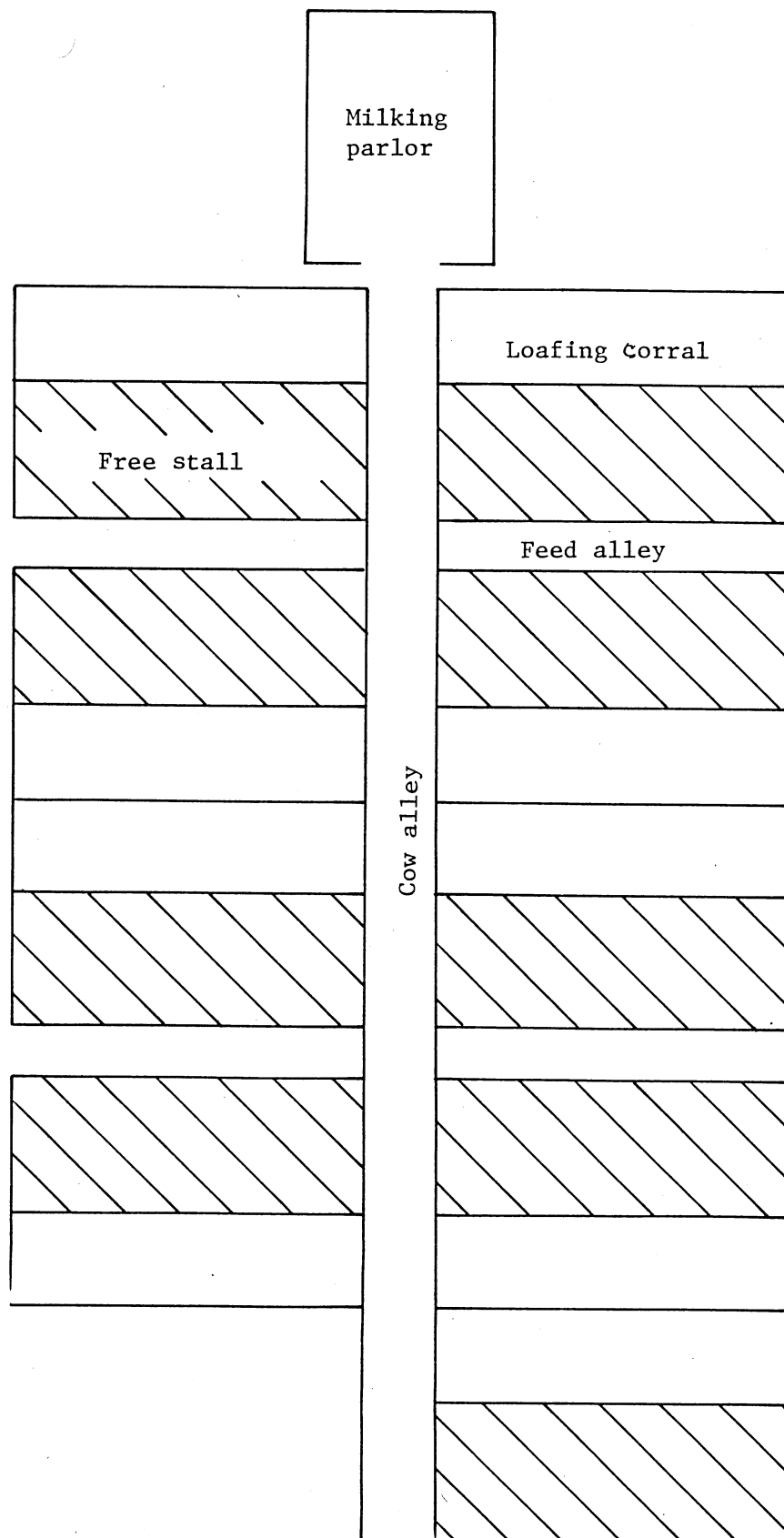
Appendix Figure A-4. Illustration of a Dry Lot Corral Housing Unit



Appendix Figure A-5. Illustration of a Double Free Stall Housing Unit



Appendix Figure A-6. Illustration of a Typical Dry Lot Corral Housing Configuration Including Cow and Feed Alleys



Appendix Figure A-7. Illustration of a Typical Free Stall Housing Configuration Including Cow and Feed Alleys

Appendix Table A-1: Derivation of Milking Parlor Construction Costs, from Elemental Component Specifications and Costs, by Parlor Classification.

Parlor code ^{a/}	Overall dimension (feet)	Total square feet	Material ^{b/}	Comment	Dimension (feet)	Quantity	Square or linear feet	Unit price range		Design price	Component cost	Total cost	
								Low	High				
Side-Opening								-----dollars-----					
SO ₃₋₁	45x26	1,170	Roof		45x26	1	1,170	2.45	3.00	2.70	3,159		
			Concrete	Pit and stalls	45x14	1	630	1.10	1.30	1.20	756		
				Other floor	45x12	1	540	.90	1.00	.92	497		
			Wall	Side	45x6	2	540	2.45	2.75	2.60	1,404		
				Front	18x9	1	162	2.45	2.75	2.60	421		
			Fence	3 rail galvanized	45x20	2	110	3.95	5.50	4.50	495		
			Shutters	3' high/10' sections		8				100.00	800		
			Plumbing								1,000		
			Electrical								2,800		
			Plaster and tile								700		
													<u>12,212</u>
			SO ₃₋₂	53x26	1,378	Roof		53x26	1	1,378	2.45	3.00	2.70
Concrete	Pit and stalls	53x14				1	742	1.10	1.30	1.20	890		
	Other floor	53x12				1	636	.90	1.00	.92	585		
Wall	Side	53x6				2	636	2.45	2.75	2.60	1,654		
	Front	18x9				1	162	2.45	2.75	2.60	421		
Fence	3 rail galvanized	53x20				2	126	3.95	5.50	4.50	567		
Shutters	3' high/10' sections					10				100.00	1,000		
Plumbing	+ 200 for wash stalls										1,200		
Electrical											2,800		
Plaster and tile											700		
													<u>13,538</u>
SO ₄₋₁	54x26	1,404				Roof		54x26	1	1,404	2.45	3.50	2.70
			Concrete	Pit and stalls	54x14	1	756	1.10	1.30	1.20	907		
				Other floor	54x12	1	648	.90	1.00	.92	596		
			Wall	Side	54x6	2	648	2.45	2.75	2.60	1,685		
				Front	18x9	1	162	2.45	2.75	2.60	421		
			Fence	3 rail galvanized	54x20	2	128	3.95	5.50	4.50	576		
			Shutters			10				100.00	1,000		
			Plumbing	+ \$200 per set of stalls							1,200		
			Electrical								2,800		
			Plaster and tile								900		
													<u>13,876</u>

(continued)

Appendix Table A-1 (continued)

Parlor code ^{a/}	Overall dimension (feet)	Total square feet	Material ^{b/}	Comment	Dimension (feet)	Quantity	Square or linear feet	Unit price range		Design price	Component cost	Total cost
								Low	High			
-----dollars-----												
SO ₄ -2	62x26	1,612	Roof		62x26	1	1,612	2.45	3.50	2.70	4,352	
			Concrete	Pit and stalls	62x14	1	868	1.10	1.30	1.20	1,042	
				Other floor	62x12	1	744	.90	1.00	.92	684	
			Wall	Side	62x6	2	744	2.45	2.75	2.60	1,934	
				Front	18x9	1	162	2.45	2.75	2.60	421	
			Fence	3 rail galvanized	62x20	2	144	3.95	5.50	4.50	677	
			Shutters			12					1,200	
			Plumbing	+ \$200 for wash stalls							1,400	
			Electrical								2,800	
			Plaster and tile								900	
<u>Herringbone</u>												
HB ₅	32x30	960	Roof		32x30	1	960	2.45	3.00	2.70	2,592	
			Concrete	Pit and stalls	32x18	1	576	1.10	1.30	1.20	691	
				Other floor	32x12	1	384	.90	1.00	.92	353	
			Wall	Side	32x6	2	384	2.45	2.75	2.60	998	
				Front	22x9	1	198	2.45	2.75	2.60	515	
			Fence	3 rail galvanized	32	2	64	3.95	5.50	4.50	288	
			Shutters			6				100.00	600	
			Plumbing								900	
			Electrical								2,300	
			Plaster and tile								500	
HB ₈	42x36	1,512	Roof		42x36	1	1,512	2.45	3.00	2.70	4,082	
			Concrete	Pit and stalls	42x18	1	756	1.10	1.30	1.20	907	
				Other floors	42x18	1	756	.90	1.00	.92	696	
			Walls	Side	42x6	2	504	2.45	2.75	2.60	1,310	
				Front	28x9	1	252	2.45	2.75	2.60	655	
			Fence	3 rail galvanized	42	4	168	3.95	5.50	4.50	756	
			Shutters			8				100.00	800	
			Plumbing								1,000	
			Electrical								2,500	
			Plaster and tile								800	

(continued)

Appendix Table A-1 (continued)

Parlor code ^{a/}	Overall dimension (feet)	Total square feet	Material ^{b/}	Comment	Dimension (feet)	Quantity	Square or linear feet	Unit price range		Design price	Component cost	Total cost	
								Low	High				
-----dollars-----													
HB ₁₀	49x36	1,764	Roof		49x36	1	1,764	2.45	3.00	2.70	4,763		
			Concrete	Pit and stall	49x18	1	882	1.10	1.30	1.20	1,058		
				Other floor	49x18	1	882	.90	1.00	.92	811		
			Wall	Side	49x6	2	588	2.45	2.75	2.60	1,529		
				Front	28x9	1	252	2.45	2.75	2.60	655		
			Fence	3 rail galvanized	49	4	196	3.95	5.50	4.50	882		
			Shutter			8					100.00	800	
			Plumbing									1,000	
			Electrical									2,700	
			Plaster and tile									1,000	
													15,199
HB ₁₂ ^{c/}	60x36	2,160	Roof		60x36	1	2,160	2.45	3.00	2.70	5,832		
			Concrete	Pit and stall	60x18	1	1,080	1.10	1.30	1.20	1,296		
				Other floor	60x18	1	1,080	.90	1.00	.92	994		
			Wall	Side	60x6	2	720	2.45	2.75	2.60	1,872		
				Front	28x9	1	252	2.45	2.75	2.60	655		
			Fence	3 rail galvanized	60	4	240	3.95	5.50	4.50	1,080		
			Shutter			10					100.00	1,000	
			Plumbing									1,000	
			Electrical									2,900	
			Plaster and tile									1,400	
													18,029
HB ₁₆ ^{c/}	74x36	2,664	Roof		74x36	1	2,664	2.45	3.00	2.70	7,193		
			Concrete	Pit and stall	74x18	1	1,332	1.10	1.30	1.20	1,598		
				Other floor	74x18	1	1,332	.90	1.00	.92	1,225		
			Wall	Side	74x6	2	888	2.45	2.75	2.60	2,309		
				Front	28x9	1	252	2.45	2.75	2.60	655		
			Fence	3 rail galvanized	74	4	296	3.95	5.50	4.50	1,332		
			Shutter			14					100.00	1,400	
			Plumbing									1,200	
			Electrical									3,000	
			Plaster and tile									1,900	
													21,813

(continued)

Appendix Table A-1 (continued)

Parlor code ^{a/}	Overall dimension (feet)	Total square feet	Material ^{b/}	Comment	Dimension (feet)	Quantity	Square or linear feet	Unit price range		Design price	Component cost	Total cost	
								Low	High				
								-----dollars-----					
<u>Polygon</u>													
P 24	48x45	2,160	Roof		48x45	1	2,160	2.45	3.00	2.70	5,832		
			Concrete	Pit and stall	48x27	1	1,296	1.10	1.30	1.20	1,555		
				Other floor	48x18	1	864	.90	1.00	.92	795		
			Wall	Side ^{d/}	48x7.5	2	720	2.45	2.75	2.60	1,872		
			Fence	3 rail galvanized	20	12	240	3.95	5.50	4.50	1,080		
			Shutter			4				100.00	400		
			Plumbing								1,000		
			Electrical								2,900		
			Plaster and tile								2,000		
											<u>17,434</u>		
P 32	62x56	3,472	Roof		62x56	1	3,472	2.45	3.00	2.70	9,374		
			Concrete	Pit and stall	62x38	1	2,356	1.10	1.30	1.20	2,827		
				Other floor	62x18	1	1,116	.90	1.00	.92	1,027		
			Wall	Side ^{d/}	62x7.5	2	930	2.45	2.75	2.60	2,418		
			Fence	3 rail galvanized	27	12	324	3.95	5.50	4.50	1,503		
			Shutter			6				100.00	600		
			Plumbing								1,200		
			Electrical								3,000		
			Plaster and tile								2,300		
											<u>24,249</u>		

^{a/} Parlor Code: Letter(s) identify parlor classification; the numbers identify the number of stalls per side. In the case of side opening parlors, the second number identifies the type of washing operation, i.e., 1 indicates stimulation stall only and 2 indicates addition of wash stalls. All herringbone and polygon parlors, except the double 5 herringbone, have double exit alleys.

^{b/} The plumbing, electrical, plaster and tile categories are dairy specific. The chosen values are intended only to generalize the approximate costs for each of the alternative parlors.

^{c/} Herringbone double 12 and 16 parlors are split with exits at the center and the end.

^{d/} The side wall height of 7.5 feet is an average for both walls given that one wall is 9 feet high and the other is 6 feet high with 3 feet of shutters.

Source: Derived from interviews with contractors.

Appendix Table A-2: Derivation of Drip Pen Construction Costs From Elemental Component Specifications and Costs, by Milking Parlor Configuration.^{a/}

Drip Pen for Side-Opening Parlors SO ₃₋₁ and SO ₄₋₁												
Housing size correspondence	Overall dimension (feet)	Total square feet	Material	Comments	Dimension (feet)	Quantity	Square or Linear feet	Unit price range		Design price	Component costs	Total costs
								Low	High			
								-----dollars-----				
80 cows	33x26	858	Roof		32x26	1	858	2.45	3.00	2.70	2,317	
			Concrete	Pen, alleys and other	32x26	1	858	.90	1.00	.92	789	
			Wall	9' ave. height	9x33	2	594	2.45	2.75	2.60	1,544	
			Fence	3 rail galvanized	25	2	50	3.95	5.50	4.50	225	<u>4,875</u>
100 cows	37x26	962	Roof		37x26	1	962	2.45	3.00	2.70	2,597	
			Concrete	Pen, alleys and other	37x26	1	962	.90	1.00	.92	885	
			Wall	9' ave. height	9x37	2	666	2.45	2.75	2.60	1,732	
			Fence	3 rail galvanized	29	2	58	3.95	5.50	4.50	261	<u>5,475</u>
120 cows	43x26	1,118	Roof		43x26	1	1,118	2.45	3.00	2.70	3,019	
			Concrete	Pen, alleys and other	43x26	1	1,118	.90	1.00	.92	1,029	
			Wall	9' ave. height	9x43	2	774	2.45	2.75	2.60	2,012	
			Fence	3 rail galvanized	35	2	70	3.95	5.50	4.50	315	<u>6,375</u>
110 cows	40x26	1,040	Roof		40x26	1	1,040	2.45	3.00	2.70	2,808	
			Concrete	Pen, alleys and other	40x26	1	1,040	.90	1.00	.92	957	
			Wall	9' ave. height	9x40	2	720	2.45	2.75	2.60	1,872	
			Fence	3 rail galvanized	32	2	64	3.95	5.50	4.50	288	<u>5,925</u>
130 cows	47x26	1,222	Roof		47x26	1	1,222	2.45	3.00	2.70	3,299	
			Concrete	Pen, alleys and other	47x26	1	1,222	.90	1.00	.92	1,124	
			Wall	9' ave. height	9x47	2	846	2.45	2.75	2.60	2,200	
			Fence	3 rail galvanized	39	2	78	3.95	5.50	4.50	351	<u>6,974</u>

(continued)

Appendix Table A-2 (continued)

Drip Pen for Herringbone Parlors (Single Exit Lanes)												
Housing size correspondence	Overall dimension (feet)	Total square feet	Material	Comments	Dimension (feet)	Quantity	Square or Linear feet	Unit price range		Design price	Component costs	Total costs
								Low	High			
									-----dollars-----			
80 cows	25x30	750	Roof		25x30	1	750	2.45	3.00	2.70	2,025	<u>4,110</u>
			Concrete	Pen, alleys and other	25x30	1	750	.90	1.00	.92	690	
			Wall	9' ave. height	9x25	2	450	2.45	2.75	2.60	1,170	
			Fence	3 rail galvanized	25	2	50	3.95	5.50	4.50	225	
100 cows	28x30	840	Roof		28x30	1	840	2.45	3.00	2.70	2,268	<u>4,603</u>
			Concrete	Pen, alleys and other	28x30	1	840	.90	1.00	.92	773	
			Wall	9' ave. height	9x28	2	504	2.45	2.75	2.60	1,310	
			Fence	3 rail galvanized	28	2	56	3.95	5.50	4.50	252	
120 cows	34x30	1,020	Roof		34x30	1	1,020	2.45	3.00	2.70	2,754	<u>5,590</u>
			Concrete	Pen, alleys and other	34x30	1	1,020	.90	1.00	.92	938	
			Wall	9' ave. height	9x34	2	612	2.45	2.75	2.60	1,591	
			Fence	3 rail galvanized	34	2	68	3.95	5.50	4.50	306	
110 cows	31x30	930	Roof		31x30	1	930	2.45	3.00	2.70	2,511	<u>5,096</u>
			Concrete	Pen, alleys and other	31x30	1	930	.90	1.00	.92	856	
			Wall	9' ave. height	9x31	2	558	2.45	2.75	2.60	1,451	
			Fence	3 rail galvanized	31	2	62	3.95	5.50	4.50	279	
130 cows	36x30	1,080	Roof		36x30	1	1,080	2.45	3.00	2.70	2,916	<u>5,918</u>
			Concrete	Pen, alleys and other	36x30	1	1,080	.90	1.00	.92	994	
			Wall	9' ave. height	9x36	2	648	2.45	2.75	2.60	1,685	
			Fence	3 rail galvanized	36	2	72	3.95	5.50	4.50	324	

(continued)

Appendix Table A-2 (continued)

Drip Pen for Herringbone Parlors (Double Exit Lanes)												
Housing size correspondence	Overall dimension (feet)	Total square feet	Material	Comments	Dimension (feet)	Quantity	Square or linear feet	Unit price range		Design price	Component costs	Total costs
								Low	High			
-----dollars-----												
80 cows	25x36	900	Roof		25x36	1	900	2.45	3.00	2.70	2,430	
			Concrete	Pen, alleys and other	25x36	1	900	.90	1.00	.92	828	
			Wall	9' ave. height	9x25	2	450	2.45	2.75	2.60	1,170	
			Fence	3 rail galvanized	25	2	50	3.95	5.50	4.50	225	
												<u>4,653</u>
100 cows	28x36	1,008	Roof		28x36	1	1,008	2.45	3.00	2.70	2,722	
			Concrete	Pen, alleys and other	28x36	1	1,008	.90	1.00	.92	927	
			Wall	9' ave. height	9x38	2	504	2.45	2.75	2.60	1,310	
			Fence	3 rail galvanized	28	2	56	3.95	5.50	4.50	252	
												<u>5,211</u>
120 cows	34x36	1,224	Roof		34x36	1	1,224	2.45	3.00	2.70	3,305	
			Concrete	Pen, alleys and other	34x36	1	1,224	.90	1.00	.92	1,126	
			Wall	9' ave. height	9x34	2	612	2.45	2.75	2.60	1,591	
			Fence	3 rail galvanized	34	2	68	3.95	5.50	4.50	306	
												<u>6,328</u>
110 cows	31x36	1,116	Roof		31x36	1	1,116	2.45	3.00	2.70	3,013	
			Concrete	Pen, alleys and other	31x36	1	1,116	.90	1.00	.92	1,027	
			Wall	9' ave. height	9x31	2	558	2.45	2.75	2.60	1,451	
			Fence	3 rail galvanized	31	2	62	3.95	5.50	4.50	279	
												<u>5,761</u>
130 cows	36x36	1,296	Roof		36x36	1	1,296	2.45	3.00	2.70	3,499	
			Concrete	Pen, alleys and other	36x36	1	1,296	.90	1.00	.92	1,192	
			Wall	9' ave. height	9x36	2	648	2.45	2.75	2.60	1,685	
			Fence	3 rail galvanized	36	2	72	3.95	5.50	4.50	324	
												<u>6,700</u>

(continued)

Appendix Table A-2 (continued)

Drip Pen for Polygon Parlors (Double Exit Lanes) ^{b/}												
Housing size correspondence	Overall dimension (feet)	Total square feet	Material	Comments	Dimension (feet)	Quantity	Square or linear feet	Unit price range		Design price	Component costs	Total costs
								Low	High			
<u>24 Polygon</u>								-----dollars-----				
120 cows	39x45	1,755	Roof		39x45	1	1,755	2.45-3.00		2.70	4,739	
			Concrete	Pen, alleys and other	39x45	1	1,755	.90-1.00		.92	1,615	
			Wall	9' ave. height	9x39	2	702	2.45-2.75		2.60	1,825	
			Fence	3 rail galvanized	39	2	78	3.95-5.50		4.50	<u>351</u>	<u>8,529</u>
<u>32 Polygon</u>												
120 cows	29x56	1,624	Roof		29x56	1	1,624	2.45-3.00		2.70	4,385	
			Concrete	Pen, alleys and other	29x56	1	1,624	.90-1.00		.92	1,494	
			Wall	9' ave. height	9x29	2	522	2.45-2.75		2.60	1,357	
			Fence	3 rail galvanized	29	2	58	3.95-5.50		4.50	<u>261</u>	<u>7,497</u>
<u>24 Polygon</u>												
130 cows	41x45	1,845	Roof		41x45	1	1,845	2.45-3.00		2.70	4,982	
			Concrete	Pen, alleys and other	41x45	1	1,845	.90-1.00		.92	1,697	
			Wall	9' ave. height	9x41	2	738	2.45-2.75		2.60	1,919	
			Fence	3 rail galvanized	41	2	82	3.95-5.50		4.50	<u>369</u>	<u>8,967</u>
<u>32 Polygon</u>												
130 cows	32x56	1,792	Roof		32x56	1	1,792	2.45-3.00		2.70	4,838	
			Concrete	Pen, alleys and other	32x56	1	1,792	.90-1.00		.92	1,649	
			Wall	9' ave. height	9x32	2	576	2.45-2.75		2.60	1,498	
			Fence	3 rail galvanized	32	2	64	3.95-5.50		4.50	<u>288</u>	<u>8,273</u>

a/ Drip pens are constructed to hold 1/2 a string at 13 square feet per cow.

b/ Double the total cost estimates to obtain total drip pen costs for a complete polygon parlor.

Source: Derived from interviews with contractors.

Appendix Table A-3: Derivation of Wash Pen Construction Costs from Elemental Component Specifications and Costs, by Milking Parlor Configuration.^{a/b/}

Wash Pen for Side-Opening Parlors SO ₃₋₁ and SO ₄₋₁												
Housing correspondence c/	Overall dimension (feet)	Total square feet	Material	Comment	Dimension (feet)	Quantity	Square or linear feet	Unit price range		Design price	Component cost	Total cost
								Low	High			
								-----dollars-----				
80 cows	73x26	1,898	Concrete	Pen and alleys	73x26	1	1,898	.90	1.00	.92	1,746	
			Wall	7' ave. height (6' end)	(7x64)+(6x26)	2/1	1,052	2.45	2.75	2.60	2,735	
			Washers	Sprinklers with 6' Ø		60		50.00	55.00	50.00	3,000	
				10 hp. booster and timer		1		1,104.00	1,225.00	1,200.00	1,200	
				Holding tank		1		1,500.00	2,800.00	1,700.00	1,100	
			Fence	3 rail galvanized	64	2	128	3.95	5.50	4.50	576	
			Rail gate	Narrow span		2		90.00	130.00	110.00	220	
			Gate	4 rails		2		55.00	120.00	65.00	130	
											10,707	
100 cows	89x26	2,314	Concrete	Pen and alleys	89x26	1	2,314	.90	1.00	.92	2,129	
			Wall	7' ave. height (6' end)	(7x80)+(6x26)	2/1	1,276	2.45	2.75	2.60	3,318	
			Washers	Sprinklers with 6' Ø		70		50.00	55.00	50.00	3,500	
				15 hp. booster and timer		1		1,289.00	1,500.00	1,400.00	1,400	
				Holding tank		1				1,900.00	1,900	
			Fence	3 rail galvanized	80	2	160	3.95	5.50	4.50	720	
			Rail gate	Narrow span		2		90.00	130.00	110.00	220	
			Gate	4 rails		2				65.00	130	
											13,316	
120 cows	105x26	2,730	Concrete	Pen and alleys	105x26	1	2,730	.90	1.00	.92	2,512	
			Wall	7' ave. height (6' end)	(7x96)+(6x26)	2/1	1,500	2.45	2.75	2.60	3,900	
			Washers	Sprinklers with 6' Ø		85		50.00	55.00	50.00	4,250	
				20 hp. booster and timer		1		1,430.00	1,680.00	1,560.00	1,560	
				Holding tank		1				2,100.00	2,100	
			Fence	3 rail galvanized	96	2	192	3.95	5.50	4.50	864	
			Rail gate	Narrow span		2		90.00	130.00	110.00	220	
			Gate	4 rails		2		55.00	120.00	65.00	130	
											15,536	

(continued)

Appendix Table A-3 (continued)

Housing correspondence c/	Overall dimension (feet)	Total square feet	Material	Comment	Dimension (feet)	Quantity	Square or linear feet	Unit price range		Design price	Component cost	Total cost
								Low	High			
								-----dollars-----				
110 cows	98x26	2,522	Concrete	Pen and alleys	97x26	1	2,522	.90	1.00	.92	2,320	
			Wall	7' ave. height (6' end)	(7x88)+(6x26)	2/1	1,388	2.45	2.75	2.60	3,609	
			Washers	Sprinklers with 6' Ø		80		50.00	55.00	50.00	4,000	
				15 hp. booster and timer				1,289.00	1,500.00	1,400.00	1,400	
				Holding tank						1,900.00	1,900	
			Fence	3 rail galvanized	88	2	176	3.95	5.50	4.50	792	
			Rail gate	Narrow span		2		90.00	130.00	110.00	220	
			Gate	4 rails		2		55.00	120.00	65.00	130	
											14,371	
130 cows	113x26	2,938	Concrete	Pen and alleys	113x26	1	2,938	.90	1.00	.92	2,703	
			Wall	7' ave. height (6' end)	(7x104)+(6x26)	2/1	1,612	2.45	2.75	2.60	4,191	
			Washers	Sprinklers with 6' Ø		90		50.00	55.00	50.00	4,500	
				20 hp. booster and timer						1,560.00	1,560	
				Holding tank						2,100.00	2,100	
			Fence	3 rail galvanized	104	2	208	3.95	5.50	4.50	936	
			Rail gate	For narrow wash pen		2		90.00	130.00	110.00	220	
			Gate	4 rails		2		55.00	120.00	65.00	130	
											16,340	

(continued)

Appendix Table A-3 (continued)

Wash Pen for Double 8-16 Herringbone Parlors (Double Exit Lanes)												
Housing correspondence c/	Overall dimension (feet)	Total square feet	Material	Comment	Dimension (feet)	Quantity	Square or linear feet	Unit price range		Design price	Component cost	Total cost
								Low	High			
								-----dollars-----				
80 cows	62x36	2,232	Concrete	Pen and alleys	62x36	1	2,232	.90	1.00	.92	2,053	
			Wall	7' ave. height (6' end)	(7x53)+(6x36)	2/1	58	2.45	2.75	2.60	2,491	
			Washer	Sprinklers with 6' Ø		50	50.00	55.00	50.00	2,500		
				10 hp. booster and timer			1,104.00	1,225.00	1,200.00	1,200		
				Holding tank					1,700.00	1,700		
			Fence	3 rail galvanized	53	2	106	3.95	5.50	4.50	477	
			Rail gate	For narrow wash pen		2		90.00	130.00	110.00	220	
			Gate	4 rails		2		55.00	120.00	65.00	130	
											10,771	
100 cows	76x36	2,736	Concrete	Pen and alleys	76x36	1	2,736	.90	1.00	.92	2,517	
			Wall	7' ave. height (6' end)	(7x67)+(6x36)	2/1	1,154	2.45	2.75	2.60	3,000	
			Washer	Sprinklers with 6' Ø		60	50.00	55.00	50.00	3,000		
				15 hp. booster and timer			1,289.00	1,500.00	1,400.00	1,400		
				Holding tank					1,900.00	1,900		
			Fence	3 rail galvanized	67	2	134	3.95	5.50	4.50	603	
			Rail gate	For narrow wash pen		2		90.00	130.00	110.00	220	
			Gate	4 rails		2		55.00	120.00	65.00	130	
											12,871	
120 cows	89x36	3,204	Concrete	Pen and alleys	89x36	1	3,204	.90	1.00	.92	2,948	
			Wall	7' ave. height (6' end)	(7x80)+(6x36)	2/1	1,336	2.45	2.75	2.60	3,474	
			Washer	Sprinklers with 6' Ø		70	50.00	55.00	50.00	3,500		
				20 hp. booster and timer			1,430.00	1,680.00	1,560.00	1,560		
				Holding tank					2,100.00	2,100		
			Fence	3 rail galvanized	80	2	160	3.95	5.50	4.50	720	
			Rail gate	For narrow wash pen		2		90.00	130.00	110.00	220	
			Gate	4 rails		2		55.00	120.00	65.00	130	
											14,651	

(continued)

Appendix Table A-3 (continued)

Housing correspondence c/	Overall dimension (feet)	Total square feet	Material	Comment	Dimension (feet)	Quantity	Square or linear feet	Unit price range		Design price	Component cost	Total cost
								Low	High			
-----dollars-----												
110 cows	82x36	2,952	Concrete	Pen and alleys	82x36	1	2,952	.90	1.00	.92	2,716	
			Wall	7' ave. height (6' end)	(7x73)+(6x36)	2/1	1,238	2.45	2.75	2.60	3,219	
			Washer	Sprinklers with 6' Ø		65		50.00	55.00	50.00	3,250	
				15 hp. booster and timer				1,289.00	1,500.00	1,400.00	1,400	
				Holding tank						1,900.00	1,900	
			Fence	3 rail galvanized	73	2	146	3.95	5.50	4.50	657	
			Rail gate	For narrow wash pen		2		90.00	130.00	110.00	220	
			Gate	4 rail		2		55.00	120.00	65.00	130	
												13,491
130 cows	96x36	3,456	Concrete	Pen and alleys	96x36	1	3,456	.90	1.00	.92	3,180	
			Wall	7' ave. height (6' end)	(7x87)+(6x36)	2/1	1,434	2.45	2.75	2.60	3,728	
			Washer	Sprinklers with 6' Ø		80		50.00	55.00	50.00	4,000	
				20 hp. booster and timer				1,430.00	1,680.00	1,560.00	1,560	
				Holding tank						2,100.00	2,100	
			Fence	3 rail galvanized	87	2	174	3.95	5.50	4.50	783	
			Rail gate	For narrow wash pen		2		90.00	130.00	110.00	220	
			Gate	4 rails		2		55.00	120.00	65.00	130	
												15,701

(continued)

Appendix Table A-3 (continued)

Wash Pen for Double 5 Herringbone Parlor (Single Exit Lanes) ^{a/,b/}												
Housing correspondence c/	Overall dimension (feet)	Total square feet	Material	Comment	Dimension (feet)	Quantity	Square or linear feet	Unit price range		Design price	Component cost	Total cost
								Low	High			
-----dollars-----												
80 cows	62x30	1,860	Concrete	Pen and alleys	62x30	1	1,860	.90	1.00	.92	1,711	
			Wall	7' ave. height (6' end)	(7x53)+(6x30)	2/1	922	2.45	2.75	2.60	2,397	
			Washer	Sprinklers with 6' Ø		50		50.00	55.00	50.00	2,500	
				10 hp. booster and timer				1,104.00	1,225.00	1,200.00	1,200	
				Holding tank				1,500.00	2,800.00	1,700.00	1,700	
			Fence	3 rail galvanized	53	2	106	3.95	5.50	4.50	477	
			Rail gate	For narrow wash pens		2		90.00	130.00	110.00	220	
			Gate	4 rails		2		55.00	120.00	65.00	130	
												<u>10,335</u>
100 cows	76x30	2,280	Concrete	Pen and alleys	76x30	1	2,280	.90	1.00	.92	2,098	
			Wall	7' ave. height (6' end)	(7x67)+(6x30)	2/1	1,118	2.45	2.75	2.60	2,907	
			Washer	Sprinkler with 6' Ø		60		50.00	55.00	50.00	3,000	
				15 hp. booster and timer				1,289.00	1,500.00	1,400.00	1,400	
				Holding tank							1,900	
			Fence	3 rail galvanized	67	2	134	3.95	5.50	4.50	603	
			Rail gate	For narrow wash pens		2		90.00	130.00	110.00	220	
			Gate	4 rails		2		55.00	120.00	65.00	130	
												<u>12,257</u>
120 cows	89x30	2,670	Concrete	Pen and alleys	89x30	1	2,670	.90	1.00	.92	2,456	
			Wall	7' ave. height (6' end)	(7x80)+(6x30)	2/1	1,300	2.45	2.75	2.60	3,380	
			Washer	Sprinklers with 6' Ø		70		50.00	55.00	50.00	3,500	
				20 hp. booster and timer				1,430.00	1,680.00		1,560	
				Holding tank							2,100	
			Fence	3 rail galvanized	80	2	160	3.95	5.50	4.50	720	
			Rail gate	For narrow wash pen		2		90.00	130.00	110.00	220	
			Fate	4 rails		2		55.00	120.00	65.00	130	
												<u>14,066</u>

(continued)

Appendix Table A-3 (continued)

Housing correspondence c/	Overall dimension (feet)	Total square feet	Material	Comment	Dimension (feet)	Quantity	Square or linear feet	Unit price range		Design price	Component cost	Total cost	
								Low	High				
-----dollars-----													
110 cows	82x30	2,460	Concrete	Pen and alleys	82x30	1	2,460	.90	1.00	.92	2,263		
			Wall	7' ave. height (6' end)	(7x73)+(6x30)	2/1	1,202	2.45	2.75	2.60	3,125		
			Washer	Sprinklers with 6' Ø		65		50.00	55.00	50.00	3,250		
				15 hp. booster and timer				1,289.00	1,500.00	1,400.00	1,400		
				Holding tank						1,900.00	1,900		
			Fence	3 rail galvanized	73	2	146	3.95	5.50	4.50	657		
			Rail gate	For narrow wash pens		2		90.00	130.00	110.00	220		
			Gate	4 nails		2		55.00	120.00	65.00	130		
													<u>12,945</u>
130 cows	96x30	2,880	Concrete	Pen and alleys	96x30	1	2,880	.90	1.00	.92	2,650		
			Wall	7' ave. height (6' end)	(7x87)+(6x30)	2/1	1,398	2.45	2.75	2.60	3,635		
			Washer	Sprinklers with 6' Ø		80		50.00	55.00	50.00	4,000		
				20 hp. booster and timer				1,430.00	1,680.00	1,560.00	1,560		
				Holding tank						2,100.00	2,100		
			Fence	3 rail galvanized	87	2	174	3.95	5.50	4.50	783		
			Rail gate	For narrow wash pen		2		90.00	130.00	110.00	220		
			Gate	4 rails		2		55.00	120.00	65.00	130		
													<u>15,077</u>

(continued)

Appendix Table A-3 (continued)

Appendix Table A-5 (continued)

Wash Pens for Polygon Parlors (Double Exit Lanes) ^{d/}												
Housing correspondence c/	Overall dimension (feet)	Total square feet	Material	Comment	Dimension (feet)	Quantity	Square or linear feet	Unit price range		Design price	Component cost	Total cost
								Low	High			
								-----dollars-----				
<u>Polygon 24</u>												
120 cows	80x45	3,600	Concrete	Pen and alleys	80x45	1	3,600	.90	1.00	.92	3,312	
			Wall	7' ave. height (6' end)	(7x71)+(6x45)	2/1	1,264	2.45	2.75	2.60	3,286	
			Washers	Sprinklers with 6' Ø		65		50.00	55.00	50.00	3,250	
				20 hp. booster and timer				1,430.00	1,680.00	1,560.00	1,560	
				Holding tank (1/2)						1,400.00	1,400	
			Fence	3 rail galvanized	71	2	142	3.95	5.50	4.50	639	
			Rail gate	wide span		2		150.00	200.00	175.00	350	
			Gate	4 rail		2		55.00	120.00	65.00	130	
												<u>13,927</u>
<u>Polygon 32</u>												
120 cows	60x56	3,396	Concrete	Pen and alleys	60x56	1	3,396	.90	1.00	.92	3,124	
			Wall	7' ave. height (6' end)	(7x51)+(6x56)	2/1	1,050	2.45	2.75	2.60	2,730	
			Washers	Sprinklers with 6' Ø		63		50.00	55.00	50.00	3,150	
				20 hp. booster and timer				1,430.00	1,680.00	1,560.00	1,560	
				Holding tank (1/2)						1,400.00	1,400	
			Fence	3 rail galvanized	51	2	102	3.95	5.50	4.50	459	
			Rail gate	Wide span		2		150.00	200.00	175.00	350	
			Gate	4 rail		2		55.00	120.00	65.00	130	
												<u>12,903</u>

(continued)

Appendix Table A-3 (continued)

Housing correspondence c/	Overall dimension (feet)	Total square feet	Material	Comment	Dimension (feet)	Quantity	Sample or linear feet	Unit price range		Design price	Component cost	Total cost
								Low	High			
								-----dollars-----				
<u>Polygon 24</u>												
130 cows	86x45	3,870	Concrete	Pen and alleys	86x45	1	3,870	.90	1.00	.92	3,560.40	
			Wall	7' ave. height (6' end)	(7x77)+(6x45)	2/1	1,348	2.45	2.75	2.60	3,504.80	
			Washers	Sprinklers with 6' Ø		70		50.00	55.00	50.00	3,500.00	
				Booster and timer							1,560.00	
				Holding tank			1/2				1,400.00	
			Fence	3 rail galvanized	77	2	154	3.95	5.50	4.50	693.00	
			Rail gate	Wide span		2		150.00	200.00	175.00	350.00	
			Gate	4 rail		2		55.00	120.00	65.00	130.00	
												<u>14,689.20</u>
<u>Polygon 32</u>												
130	64x56	3,584	Concrete	Pen and alleys	64x56	1	3,584	90.00	1.00	.92	3,297.28	
			Wall	7' ave. height (6' end)	(7x55)+(6x56)	2/1	1,106	2.45	2.75	2.60	2,875.60	
			Washers	Sprinklers with 6 Ø		70		50.00	55.00	50.00	3,500.00	
				20 hp. booster and timer							1,560.00	
				Holding tank			1/2				1,400.00	
			Fence	3 rail galvanized	55	2	110	3.95	5.50	4.50	495.00	
			Rail gate	Wide span		2		150.00	200.00	175.00	350.00	
			Gate	4 rail		2		55.00	120.00	65.00	130.00	
												<u>13,607.88</u>

- a/ Wash pen design is based on area allocation per cow. The area per cow reported by contractors varied from over 18 to 15 square feet. These particular designs assume 16 square feet per cow.
- b/ Wash pens are designed to harmoniously integrate with parlors. Thus, a particular wash pen design corresponds with a particular parlor.
- c/ Wash pen design capacity is based on housing unit capacity. While free stall and dry lot corrals are designed for 80, 100, and 120 cows, dry lot corrals allow for some expansion. Consequently wash pens corresponding to dry lot corral housing are designed for 110 and 130 cows.
- d/ Costs are estimated for one pen only. Double the total cost estimate to obtain total wash pen cost for a complete polygon parlor.

Source: Derived from interviews with contractors and equipment suppliers.

Appendix Table A-4: Derivation of Holding Pen Construction Cost Estimates from Elemental Component Specifications.^{a/,b/}

Housing size correspondence	Overall dimension (feet)	Total square feet	Material	Comments	Dimension (feet)	Quantity	Square or linear feet'	Unit price range		Design price	Component costs	Total costs
								Low	High			
-----dollars-----												
60 cows	85x26	2,210	Roof	1/3 of length	28x26	1	728	2.45	3.00	2.70	1,966	<u>8,205</u>
			Concrete	Pen and alleys	85x26	1	2,210	.90	1.00	.92	2,033	
			Wall	7' ave. height	(7x76)+(6x26)	2/1	1,220	2.45	2.75	2.60	3,172	
			Fence	3 rail galvanized	76	2	152	3.95	5.50	4.50	684	
			Rail gate	Narrow span		2	90.00	130.00	110.00	220		
			Gate	4 rail		2	55.00	120.00	65.00	130		
100 cows	101x26	2,626	Roof	1/3 of length	33x26	1	858	2.45	3.00	2.70	2,317	<u>9,655</u>
			Concrete	Pen and alleys	101x26	1	2,626	.90	1.00	.92	2,416	
			Wall	7' ave. height	(7x92)+(6x26)	2/1	1,440	2.45	2.75	2.60	3,744	
			Fence	3 rail galvanized	92	2	184	3.95	5.50	4.50	828	
			Rail gate	Narrow span		2	90.00	130.00	110.00	220		
			Gate	4 rail		2	55.00	120.00	65.00	130		
120 cows	117x26	3,042	Roof	1/3 of length	39x26	1	1,014	2.45	3.00	2.70	2,738	<u>11,195</u>
			Concrete	Pen and alleys	117x26	1	3,042	.90	1.00	.92	2,799	
			Wall	7' ave. height	(7x108)+(6x26)	2/1	1,668	2.45	2.75	2.60	4,337	
			Fence	3 rail galvanized	108	2	216	3.95	5.50	4.50	972	
			Rail gate	Narrow span		2	90.00	130.00	110.00	220		
			Gate	4 rail		2	55.00	120.00	65.00	130		
110 cows	109x26	2,834	Roof	1/3 of length	36x26	1	936	2.45	3.00	2.70	2,527	<u>10,430</u>
			Concrete	Pen and alleys	109x26	1	2,834	.90	1.00	.92	2,607	
			Wall	7' ave. height	(7x100)+(6x26)	2/1	1,556	2.45	2.75	2.60	4,046	
			Fence	3 rail galvanized	100	2	200	3.95	5.50	4.50	900	
			Rail gate	Narrow span		2	90.00	1.30	110.00	220		
			Gate	4 rail		2	55.00	120.00	65.00	130		
130 cows	125x26	3,250	Roof	1/3 of length	41x26	1	1,066	2.45	3.00	2.70	2,878	<u>12,117</u>
			Concrete	Pen and alleys	125x26	1	3,250	.90	1.00	.92	2,990	
			Wall	7' ave. height	(7x121)+(6x26)	2/1	1,850	2.45	2.75	2.60	4,810	
			Fence	3 rail galvanized	121	2	242	3.95	5.50	4.50	1,089	
			Rail gate	Narrow span		2	90.00	130.00	110.00	220		
			Gate	4 rail		2	55.00	120.00	65.00	130		

a/ Holding pens are used with side-opening parlor with wash stalls, i.e., SO₃₋₂ and SO₄₋₂.

b/ Holding pens are constructed to hold a full string at 16 square feet per cow.

Source: Derived from interviews with contractors.

Appendix Table A-5: Milk House and Breezeway Construction Costs, by Parlor Classification in Building.^{a/,b/}

Parlor classification	Building	Dimension (feet)	Total square feet	Unit price range		Design price	Cost	Combined cost
				Low	High			
-----dollars-----								
Side-Opening (All)	Breezeway	26x6	156	11.00	13.00	12.00	1,872	
	Milkhouse, machinery room, etc.	26x20	520	17.00	21.00	19.00	9,880	11,752
Herringbone (Single exit) 5	Breezeway	30x6	180	11.00	13.00	12.00	2,160	
	Milkhouse, machinery room, etc.	30x22	660	17.00	21.00	19.00	12,540	14,700
Herringbone (Double exit) 8,10,12,16 Polygon 24, 32	Breezeway	36x8	288	11.00	13.00	12.00	3,456	
	Milkhouse, machinery room, etc.	36x26	936	17.00	21.00	19.00	17,784	21,240

a/ Construction materials for the milkhouse and breezeway vary from dairy to dairy and contractor to contractor. General design and exterior facades vary from plaster to decorative stone work, composition roofing to shake. The wide range of materials and designs makes derivation of cost estimates from detailed elemental synthesis ineffective. Consequently, construction cost estimates obtained from contractors represent cost per square foot of modest but attractive exteriors.

b/ Milkhouses and breezeways are designed to integrate with particular parlor configurations. The parlor correspondence is indicated in the first column.

Source: Derived from interviews with contractors.

Appendix Table A-6: Derivation of Dry Lot Housing Construction Cost from Elemental Component Specifications and Costs, by Housing Unit Size.^{a/}

100 Cow Corrals										
Corral dimension ^{b/}	Component	Material	Quantity	Dimension (feet)	Square or linear feet	Unit price range		Design price	Component cost	Total cost
						Low	High			
						-----dollars-----				
270'x185'	Cow stand	Concrete slab 4"	1	270x12	3,240	.42	.60	.52	1,685	
	Water trough apron	Concrete slab 4"	1	30x24	720	.42	.60	.52	374	
	Feed manager	Concrete slab 4"	1	270x3	810	.42	.60	.52	421	
	Stanchion curb	Concrete curb 16"x6"	1	270	270	2.25	2.77	2.35	635	
	Lock stanchions		108			20.50	25.35	21.50	2,322	
	Lock assembly		2			28.00	38.00	35.00	70	
	Stanchion posts	Steel posts 2-7/8"x6'6"	28			6.85	12.00	7.25	203	
	Fence	4 cable with top rail	1	270	270	2.50	3.25	2.75	743	
		4 cable with top rail	2	185	370	2.50	3.25	2.75	1,018	
	Cattle shade	40 square feet per cow	100 cows		4,000	1.05	1.30	1.10	4,400	
	Gates	4 rail	4			55.00	120.00	65.00	260	
	Water trough	16' precast concrete	1			110.00	150.00	130.00	130	
	Water line	2" PVC with trenching	1	290	290	1.00	1.20	1.05	305	
	Lights with double pole	2 mercury vapor	1			700.00	1,000.00	960.00	960	
										13,524
120 Cow Corrals										
320'x185'	Cow stand	Concrete slab 4"	1	320x12	3,840	.42	.60	.52	1,997	
	Water trough apron	Concrete slab 4"	1	30x24	720	.42	.60	.52	374	
	Feed manager	Concrete slab 4"	1	320x3	960	.42	.60	.52	499	
	Stanchion curb	Concrete curb 16"x6"	1	320	320	2.25	2.77	2.35	752	
	Lock stanchions		128			20.50	25.35	21.50	2,752	
	Lock assembly		2			28.00	38.00	35.00	70	
	Stanchion posts	Steel posts 2-7/8"x6'6"	33			6.85	12.00	7.25	239	
	Fence	4 cable with top rail	1	320	320	2.50	3.25	2.75	880	
		4 cable with top rail	2	185	370	2.50	3.25	2.75	1,018	
	Cattle shade	40 square feet per cow	120 cows		4,800	1.05	1.30	1.10	5,280	
	Gates	4 rail	4			55.00	120.00	65.00	260	
	Water trough	16' precast concrete	1			110.00	150.00	130.00	130	
	Water line	2" PVC with trenching	1	340	340	1.00	1.20	1.05	357	
	Lights with double pole	2 mercury vapor	1			700.00	1,000.00	960.00	960	
										15,568

a/ Eight additional stanchions are provided.

b/ Assumes 500 square feet per cow.

Source: Derived from interviews with contractors.

Appendix Table A-7: Derivation of Free Stall Housing Construction Costs from Elemental Component Specifications and Costs, by Housing Unit Size.^{a/}

Double 80 Cow Free Stalls										
Double free stall dimension	Component	Material	Quantity	Dimension (feet)	Square or linear feet	Unit price range		Design price	Component cost	Total cost
						Low	High			
						-----dollars-----				
200'x90'	Cow alleys	Concrete slab 4"	2	180x10	3,600	.42	.60	.52	1,872	
	Cow stand	Concrete slab 4"	2	180x11	3,960	.42	.60	.52	2,059	
	Cross alley	Concrete slab 4"	4	37x10	1,480	.42	.60	.52	770	
	Manager	Concrete slab 4"	2	200x3	1,200	.42	.60	.52	624	
	Feed alley	Concrete slab 6"	1	200x16	3,200	.60	.75	.66	2,112	
	Lock stanchions		160			20.50	25.35	21.50	3,440	
	Lock assembly		4			28.00	38.00	35.00	140	
	Stanchion posts ^{c/}	Steel post 2-7/8"x6'6"	32			6.85	12.00	7.25	232	
	Fence									
	(stall area)	4 cable with top rail	4	37	148	2.50	3.25	2.75	407	
	(loafing area)	4 cable with top rail	2	200	400	2.50	3.25	2.75	1,100	
	(loafing area)	4 cable with top rail	4	54	216	2.50	3.25	2.75	594	
	Stanchion curb	Concrete curb 16"x6"	2	200	400	2.25	2.77	2.35	940	
	Alley stall curb	Concrete curb 6"x6"x8"	4	180	720	.70	1.50	1.25	900	
	Rear stall curb	Concrete curb 8"x6"	4	180	720	.75	1.50	1.25	900	
	Stall divider curb	Concrete curb 8"x6"	184	8	1,472	.75	1.50	1.25	1,840	
	Stalls (tail to tail) ^{d/}	1-1/2" loop	180			40.00	50.00	45.00	8,100	
	Roof	Steel	2	204x42	17,136	2.25	2.45	2.35	40,270	
	Gates	4 rail	9			55.00	120.00	65.00	585	
	Water trough	8' precast concrete	8			40.00	100.00	80.00	640	
	Water line		2	160	320	1.00	1.20	1.05	336	
	Lights	Mercury vapor 275 watts	6			60.00	75.00	67.00	402	
	Electrical wire		1	290	290	1.25	2.50	1.75	508	
									<u>68,770</u>	

(continued)

Appendix Table A-7 (continued)

Double 100 Cow Free Stalls										
Double free stall dimension	Component	Material	Quantity	Dimension (feet)	Square or linear feet	Unit price range		Design price	Component cost	Total cost
						Low	High			
						-----dollars-----				
250'x90'	Cow alleys	Concrete slab 4"	2	228x10	4,560	.42	.60	.52	2,371	
	Cow stand	Concrete slab 4"	2	228x11	5,016	.42	.60	.52	2,608	
	Cross alley	Concrete slab 4"	4	37x10	1,480	.42	.60	.52	770	
	Manager	Concrete slab 4"	2	250x3	1,500	.42	.60	.52	780	
	Feed alley	Concrete slab 6"	1	250x16	4,000	.60	.75	.66	2,640	
	Lock stanchions		200			20.50	25.35	21.50	4,300	
	Lock assembly		4			28.00	38.00	35.00	140	
	Stanchion posts ^{c/}	Steel post 2-7/8x6'6"	40			6.85	12.00	7.25	290	
	Fence									
	(stall area)	4 cable with top rail	4	37	148	2.50	3.25	2.75	407	
	(loafing area)	4 cable with top rail	2	250	500	2.50	3.25	2.75	1,375	
	(loafing area)	4 cable with top rail	4	54	216	2.50	3.25	2.75	594	
	Stanchion curb	Concrete curb 16"x6"	2	250	500	2.25	2.77	2.35	1,175	
	Alley stall curb	Concrete curb 6"x6"x8"	4	228	912	.70	1.50	1.25	1,140	
	Rear stall curb	Concrete curb 8"x6"	4	228	912	.75	1.50	1.25	1,140	
	Stall divider curb	Concrete curb 8"x6"	232	8	1,856	.75	1.50	1.25	2,320	
	Stalls (tail to tail) ^{e/}	1-1/2" loop	228			40.00	50.00	45.00	10,260	
	Roof	Steel	2	254x42	21,336	2.25	2.45	2.35	50,140	
	Gates	4 rail	9			55.00	120.00	65.00	585	
	Water trough	8' precast concrete	8			40.00	100.00	80.00	640	
	Water line		2	160	320	1.00	1.20	1.05	336	
	Lights	Mercury vapor 275 Watts	6			60.00	75.00	67.00	402	
	Electrical wire		1	340		1.25	2.50	1.75	595	
									<u>85,008</u>	

(continued)

Appendix Table A-7 (continued)

Double 120 Cow Free Stalls										
Double free stall dimension	Component	Material	Quantity	Dimension (feet)	Square or linear feet	Unit price range		Design price	Component cost	Total cost
						Low	High			
						-----dollars-----				
300'x85'	Cow alley	Concrete slab 4"	2	280x10	5,600	.42	.60	.52	2,912	
	Cow stand	Concrete slab 4"	2	280x11	6,160	.42	.60	.52	3,203	
	Cross alley	Concrete slab 4"	4	37x10	1,480	.42	.60	.52	770	
	Manager	Concrete slab 4"	2	300x3	1,800	.42	.60	.52	936	
	Feed alley	Concrete slab 6"	1	300x16	4,800	.60	.75	.66	3,168	
	Lock stanchion		240			20.50	25.35	21.50	5,160	
	Lock assembly		4			28.00	38.00	35.00	140	
	Stanchion posts ^{c/}	Steel post	48			6.85	12.00	7.25	348	
	Fench									
	(stall area)	4 cable with top rail	4	37	148	2.50	3.25	2.75	407	
	(loafing area)	4 cable with top rail	2	300	600	2.50	3.25	2.75	1,650	
	(loafing area)	4 cable with top rail	4	54	216	2.50	3.25	2.75	594	
	Stanchion curb	Concrete curb 16"x6"	2	300	600	2.25	2.77	2.35	1,416	
	Alley stall curb	Concrete curb 6"x6"x8"	4	280	1,120	.70	1.50	1.25	1,400	
	Rear stall curb	Concrete curb 8"x6"	4	280	1,120	.75	1.50	1.25	1,400	
	Stall divider curb	Concrete curb 8"x6"	284	8	2,272	.75	1.50	1.25	2,840	
	Stalls (tail to tail) ^{f/}	1-1/2" loop	280			40.00	50.00	45.00	12,600	
	Roof	Steel	1	304x42	25,536	2.25	2.45	2.35	60,010	
	Gates	4 rail	9			55.00	120.00	65.00	585	
	Water trough	8' precast concrete	8			40.00	100.00	80.00	640	
	Water line		2	160	320	1.00	1.20	1.05	336	
	Lights	Mercury vapor 275 watts	8			60.00	75.00	67.00	536	
	Electrical wire		1	390		1.25	2.50	1.75	683	
									<u>101,727</u>	

^{a/} Costs are estimated for two complete free stall housing units.

^{b/} A loafing corral with 135 square feet per cow is adjacent to each free stall unit. Loafing corral cost components include perimeter fence and gates.

^{c/} Assumes roof columns replace stanchion posts every 50 feet.

^{d/} Assumes 2 rows of 45 stalls per 80 cow free stall unit.

^{e/} Assumes 2 rows of 57 stalls per 100 cow free stall unit.

^{f/} Assumes 2 rows of 70 stalls per 120 cow free stall unit.

Source: Derived from interviews with contractors.

Appendix Table A-8: Feed Alley and Cow Alley Construction Costs Per Dry Lot Corral.

Corral size	Component	Material	Quantity	Dimension (feet)	Square feet or linear feet	Unit price range		Design price	Total cost
						Low	High		
-----dollars-----									
100 cows	Feed alley	Concrete slab 6"	1	270x16	4,320	.60	.75	.66	2,851
120 cows	Feed alley	Concrete slab 6"	1	320x16	5,120	.60	.75	.66	3,379
100 cows	Cow alley	Concrete slab 4"	1	270x10	2,700	.42	.60	.52	1,404
120 cows	Cow alley	Concrete slab 4"	1	320x10	3,200	.42	.60	.52	1,664

Source: Derived from interviews with contractors.

Appendix Table A-9: Derivation of Adjustment Costs Per Dry Lot Corral for the Cereco/Scrape-Out Waste Management System: From Elemental Component Specifications and Costs, by Corral Size.

100 Cow Corral								
Component	Material	Quantity	Dimension (feet)	Square feet or linear feet	Unit price range		Design price	Component price
					Low	High		
					-----dollars-----			
Cow stand	Concrete slab 4"	1	270x2	540	.42	.60	.52	280.80
Cow stand entry	Concrete slab 4"	2	10x10	200	.42	.60	.52	104.00
Cow stand rear curb	Concrete curb 6"x6"	1	270	270	.65	1.13	.75	202.50
Fence behind stand	4 cable with top rail	1	270	270	2.50	3.25	2.75	742.50
Gates		2			55.00	120.00	65.00	130.00
					1,459.80			
120 Cow Corral								
Cow stand	Concrete slab 4"	1	320x2	640	.42	.60	.52	332.80
Cow stand entry	Concrete slab 4"	2	10x10	200	.42	.60	.75	150.00
Cow stand rear curb	Concrete curb 6"x6"	1	320	320	.65	1.13	.52	116.40
Fence behind stand	4 cable with top rail	1	320	320	2.50	3.25	2.75	880.00
Gates		2			55.00	120.00	65.00	130.00
					1,659.20			

Appendix Table A-10: Derivation of Feed Shed Construction Costs, by Herd Size.^{a/}

Herd size	Component	Dimension (feet)	Square feet	Unit price range		Design price	Component costs	Total costs
				Low	High			
				-----dollars-----				
375-624	Shed structure	80x20	1,600	2.50	3.75	3.10	4,960	
	Concrete slab 4"	80x20	1,600	.42	.60	.52	832	
	Concrete slab 6"	80x10	800	.65	1.13	.75	<u>600</u>	
								<u>6,392</u>
625-999	Shed structure	100x20	2,000	2.50	3.75	3.10	6,200	
	Concrete slab 4"	100x20	2,000	.42	.60	.52	1,040	
	Concrete slab 6"	100x10	1,000	.65	1.13	.75	<u>750</u>	
								<u>7,990</u>
1,000-1,200	Shed structure	120x20	2,400	2.50	3.75	3.10	7,440	
	Concrete slab 4"	120x20	2,400	.42	.60	.52	1,248	
	Concrete slab 6"	120x10	1,200	.65	1.13	.75	<u>900</u>	
								<u>9,588</u>

^{a/} Constructed with 6-7 cells.

Source: Derived from interviews with contractors.

APPENDIX B

TABLES B-1 THROUGH B-5

Annual Taxes and Insurance Costs for Alternative Dairy
Configurations and Herd Sizes

Appendix Table B-1: Liability Insurance Costs for Free Stall and Dry Lot Dairy Configurations, by Housing Size, Milking Herd Size, and Parlor Configuration.

Free Stall Dairy Housing Configurations																
Housing size Milk cows		Side-Opening				Herringbone									Polygon	
		Double				Double									24	32
		3-1	3-2	4-1	4-2	5		8			10		12	16		
		Auto	Auto	Auto	Auto	Swing	Conv.	Swing	Conv.	Auto	Conv.	Auto	Auto	Split	Auto	Auto
-----dollars-----																
80	320	0	0	0	0	285	285	0	0	0	0	0	0	0	0	0
80	400	356	356	356	356	356	356	356	356	356	0	0	0	0	0	0
80	480	428	428	428	428	0	0	428	428	428	0	0	0	0	0	0
80	560	499	499	499	499	0	0	499	499	499	0	0	0	0	0	0
80	640	570	570	570	570	0	0	570	570	570	0	0	0	0	0	0
100	300	0	0	0	0	267	267	0	0	0	0	0	0	0	0	0
100	400	356	356	356	356	356	356	0	0	0	0	0	0	0	0	0
100	500	446	446	446	446	0	0	0	0	0	0	446	0	0	0	0
100	600	535	535	535	535	0	0	0	0	0	535	535	0	0	0	0
100	700	0	0	624	624	0	0	0	0	0	624	624	0	0	0	0
100	800	0	0	0	0	0	0	0	0	0	713	713	0	0	0	0
100	900	0	0	0	0	0	0	0	0	0	802	802	0	0	0	0
120	360	321	321	0	0	321	321	0	0	0	0	0	0	0	0	0
120	480	428	428	428	428	0	0	428	428	428	0	0	0	0	0	0
120	600	535	535	535	535	0	0	535	535	535	535	535	535	535	0	0
120	720	0	0	0	0	0	0	642	642	642	642	642	642	642	642	642
120	840	0	0	0	0	0	0	0	0	0	748	748	748	748	0	0
120	960	0	0	0	0	0	0	0	0	0	0	0	0	855	855	855
Dry Lot Dairy Housing Configurations																
100	300	0	0	0	0	267	267	0	0	0	0	0	0	0	0	0
100	400	356	356	356	356	356	356	0	0	0	0	0	0	0	0	0
100	500	446	446	446	446	0	0	0	0	0	0	446	0	0	0	0
100	600	535	535	535	535	0	0	0	0	0	535	535	0	0	0	0
100	700	0	0	624	624	0	0	0	0	0	624	624	0	0	0	0
100	800	0	0	0	0	0	0	0	0	0	713	713	0	0	0	0
100	900	0	0	0	0	0	0	0	0	0	802	802	0	0	0	0
120	360	321	321	0	0	321	321	0	0	0	0	0	0	0	0	0
120	480	428	428	428	428	0	0	428	428	428	0	0	0	0	0	0
120	600	535	535	535	535	0	0	535	535	535	535	535	535	535	0	0
120	720	0	0	0	0	0	0	642	642	642	642	642	642	642	642	642
120	840	0	0	0	0	0	0	0	0	0	748	748	748	748	0	0
120	960	0	0	0	0	0	0	0	0	0	0	0	0	855	855	855

Source: Calculated from interviews with insurance company representatives serving the Chino dairy region.

Appendix Table B-2: Personal Property Insurance Costs for Free Stall and Dry Lot Dairy Configurations, by Housing Size, Milking Herd Size, and Parlor Configuration.

Free Stall Dairy Housing Configurations																	
Housing size	Milk cows	Side-Opening				Herringbone										Polygon	
		Double				Double										24	32
		3-1	3-2	4-1	4-2	5		8		10		12	16				
		Auto	Auto	Auto	Auto	Swing	Conv.	Swing	Conv.	Auto	Conv.	Auto	Auto	Split	Auto	Auto	
-----dollars-----																	
80	320	0	0	0	0	1392	1405	0	0	0	0	0	0	0	0	0	
80	400	1798	1785	1825	1822	1709	1723	1783	1826	1924	0	0	0	0	0	0	
80	480	1957	1943	1994	1980	0	0	1941	1985	2083	0	0	0	0	0	0	
80	560	2133	2119	2169	2156	0	0	2117	2160	2259	0	0	0	0	0	0	
80	640	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
100	300	0	0	0	0	1389	1403	0	0	0	0	0	0	0	0	0	
100	400	1684	1663	1721	1699	1592	1605	0	0	0	0	0	0	0	0	0	
100	500	2088	2066	2124	2103	0	0	0	0	0	0	2261	0	0	0	0	
100	600	0	0	2319	2298	0	0	0	0	0	2331	2456	0	0	0	0	
100	700	0	0	0	0	0	0	0	0	0	2645	0	0	0	0	0	
100	800	0	0	0	0	0	0	0	0	0	2901	3025	0	0	0	0	
100	900	0	0	0	0	0	0	0	0	0	3312	0	0	0	0	0	
120	360	1651	1622	0	0	1557	1570	0	0	0	0	0	0	0	0	0	
120	480	1897	1868	1933	1905	0	0	1878	1921	2020	0	0	0	0	0	0	
120	600	0	0	2417	2389	0	0	2362	2405	2504	2428	2553	2795	2896	0	0	
120	720	0	0	0	0	0	0	0	0	0	2828	0	3043	3144	3199	3313	
120	840	0	0	0	0	0	0	0	0	0	3092	0	3308	3408	0	0	
120	960	0	0	0	0	0	0	0	0	0	0	0	3453	3712	3825	3925	
Dry Lot Dairy Housing Configurations																	
100	300	0	0	0	0	931	944	0	0	0	0	0	0	0	0	0	
100	400	1104	1079	1140	1116	1056	1069	0	0	0	0	0	0	0	0	0	
100	500	1267	1242	1304	1279	0	0	0	0	0	0	1438	0	0	0	0	
100	600	0	0	1377	1352	0	0	0	0	0	1387	1512	0	0	0	0	
100	700	0	0	0	0	0	0	0	0	0	1625	0	0	0	0	0	
100	800	0	0	0	0	0	0	0	0	0	1724	1849	0	0	0	0	
100	900	0	0	0	0	0	0	0	0	0	1882	0	0	0	0	0	
120	360	1083	1052	0	0	989	1002	0	0	0	0	0	0	0	0	0	
120	480	1183	1152	1220	1189	0	0	1164	1207	1306	0	0	0	0	0	0	
120	600	0	0	1409	1378	0	0	1354	1397	1496	1420	1545	1787	1888	0	0	
120	720	0	0	0	0	0	0	0	0	0	1668	0	1883	1984	2044	2160	
120	840	0	0	0	0	0	0	0	0	0	1786	0	2002	2102	0	0	
120	960	0	0	0	0	0	0	0	0	0	0	0	0	2206	2267	2383	

Source: Calculated from interviews with insurance company representatives serving the Chino dairy region.

Appendix Table B-3: Personal Property Tax for Free Stall and Dry Lot Dairy Configurations, by Housing Size, Milking Herd Size, and Parlor Configuration.

Free Stall Dairy Housing Configurations																	
Housing size	Milk cows	Side-Opening				Herringbone										Polygon	
		Double				Double											
		3-1	3-2	4-1	4-2	5		8		10		12	16	24	32		
		Auto	Auto	Auto	Auto	Swing	Conv.	Swing	Conv.	Auto	Conv.	Auto	Auto	Split	Auto	Auto	
-----dollars-----																	
80	320	0	0	0	0	5271	5321	0	0	0	0	0	0	0	0	0	
80	400	6898	6757	6947	6896	6471	6521	6748	6913	7286	0	0	0	0	0	0	
80	480	7408	7357	7547	7497	0	0	7349	7513	7886	0	0	0	0	0	0	
80	560	8073	8023	8212	8162	0	0	8014	8178	8551	0	0	0	0	0	0	
80	640	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
100	300	0	0	0	0	5240	5310	0	0	0	0	0	0	0	0	0	
100	400	6376	6294	6515	6434	6025	6075	0	0	0	0	0	0	0	0	0	
100	500	7903	7822	8042	7961	0	0	0	0	0	0	8558	0	0	0	0	
100	600	0	0	8780	8699	0	0	0	0	0	8824	9296	0	0	0	0	
100	700	0	0	0	0	0	0	0	0	0	10164	0	0	0	0	0	
100	800	0	0	0	0	0	0	0	0	0	10981	11453	0	0	0	0	
100	900	0	0	0	0	0	0	0	0	0	12538	0	0	0	0	0	
120	360	6250	6141	0	0	5894	5945	0	0	0	0	0	0	0	0	0	
120	480	7180	7071	7319	7211	0	0	7109	7273	7646	0	0	0	0	0	0	
120	600	0	0	9151	9042	0	0	8941	9105	9478	9191	9463	10582	10963	0	0	
120	720	0	0	0	0	0	0	0	0	0	10705	0	11520	11902	12112	12542	
120	840	0	0	0	0	0	0	0	0	0	11706	0	12521	12902	0	0	
120	960	0	0	0	0	0	0	0	0	0	0	0	13828	14051	14481	0	
Dry Lot Dairy Housing Configurations																	
100	300	0	0	0	0	3524	3574	0	0	0	0	0	0	0	0	0	
100	400	4178	4084	4317	4224	3998	4048	0	0	0	0	0	0	0	0	0	
100	500	4796	4702	4935	4841	0	0	0	0	0	0	5445	0	0	0	0	
100	600	0	0	5213	5120	0	0	0	0	0	5252	5724	0	0	0	0	
100	700	0	0	0	0	0	0	0	0	0	6153	0	0	0	0	0	
100	800	0	0	0	0	0	0	0	0	0	6528	7000	0	0	0	0	
100	900	0	0	0	0	0	0	0	0	0	7125	0	0	0	0	0	
120	360	4100	3982	0	0	3743	3792	0	0	0	0	0	0	0	0	0	
120	480	4478	4360	4617	4500	0	0	4407	4571	4944	0	0	0	0	0	0	
120	600	0	0	5335	5218	0	0	5125	5289	5662	5376	5848	6767	7148	0	0	
120	720	0	0	0	0	0	0	0	0	0	6314	0	7129	7510	7738	8178	
120	840	0	0	0	0	0	0	0	0	0	6762	0	7578	7959	0	0	
120	960	0	0	0	0	0	0	0	0	0	0	0	8353	8581	9021	0	

Source: Calculated from tax rates obtained from Riverside and San Bernardino County Tax Assessor Offices.

Appendix Table B-4: Land Tax for Free Stall and Dry Lot Dairy Configurations, by Housing Size, Milking Herd Size, and Parlor Configuration.

Free Stall Dairy Housing Configurations																
Housing size	Milk cows	Side-Opening				Herringbone									Polygon	
		Double				Double									24	32
		3-1	3-2	4-1	4-2	5		8		10		12	16			
		Auto	Auto	Auto	Auto	Swing	Conv.	Swing	Conv.	Auto	Conv.	Auto	Auto	Split	Auto	Auto
-----dollars-----																
80	320	0	0	0	0	3180	3180	0	0	0	0	0	0	0	0	0
80	400	3975	3975	3975	3975	3975	3975	3975	3975	3975	0	0	0	0	0	0
80	480	4770	4770	4770	4770	0	0	4770	4770	4770	0	0	0	0	0	0
80	560	5565	5565	5565	5565	0	0	5565	5565	5565	0	0	0	0	0	0
80	640	6360	6360	6360	6360	0	0	6360	6360	6360	0	0	0	0	0	0
100	300	0	0	0	0	3021	3021	0	0	0	0	0	0	0	0	0
100	400	3975	3975	3975	3975	3975	3975	0	0	0	0	0	0	0	0	0
100	500	4929	4929	4929	4929	0	0	0	0	0	0	4929	0	0	0	0
100	600	6042	6042	6042	6042	0	0	0	0	0	6042	6042	0	0	0	0
100	700	0	0	6996	6996	0	0	0	0	0	6996	6996	0	0	0	0
100	800	0	0	0	0	0	0	0	0	0	7950	7950	0	0	0	0
100	900	0	0	0	0	0	0	0	0	0	8904	8904	0	0	0	0
120	360	3657	3657	0	0	3657	3657	0	0	0	0	0	0	0	0	0
120	480	4770	4770	4770	4770	0	0	4770	4770	4770	0	0	0	0	0	0
120	600	6042	6042	6042	6042	0	0	6042	6042	6042	6042	6042	6042	6042	0	0
120	720	0	0	0	0	0	0	7155	7155	7155	7155	7155	7155	7155	7155	7155
120	840	0	0	0	0	0	0	0	0	0	8427	8427	8427	8427	0	0
120	960	0	0	0	0	0	0	0	0	0	0	0	0	9540	9540	9540
Dry Lot Dairy Housing Configurations																
100	300	0	0	0	0	3021	3021	0	0	0	0	0	0	0	0	0
100	400	3975	3975	3975	3975	3975	3975	0	0	0	0	0	0	0	0	0
100	500	4929	4929	4929	4929	0	0	0	0	0	0	4929	0	0	0	0
100	600	6042	6042	6042	6042	0	0	0	0	0	6042	6042	0	0	0	0
100	700	0	0	6996	6996	0	0	0	0	0	6996	6996	0	0	0	0
100	800	0	0	0	0	0	0	0	0	0	7950	7950	0	0	0	0
100	900	0	0	0	0	0	0	0	0	0	8904	8904	0	0	0	0
120	360	3657	3657	0	0	3657	3657	0	0	0	0	0	0	0	0	0
120	480	4770	4770	4770	4770	0	0	4770	4770	4770	0	0	0	0	0	0
120	600	6042	6042	6042	6042	0	0	6042	6042	6042	6042	6042	6042	6042	0	0
120	720	0	0	0	0	0	0	7155	7155	7155	7155	7155	7155	7155	7155	7155
120	840	0	0	0	0	0	0	0	0	0	8427	8427	8427	8427	0	0
120	960	0	0	0	0	0	0	0	0	0	0	0	0	9540	9540	9540

Source: Calculated from tax rates obtained from Riverside and San Bernardino County Tax Assessor Offices.

Appendix Table B-5: Sum of Annual Taxes and Insurance Costs for Free Stall and Dry Lot Dairy Configurations, by Housing Size, Milking Herd Size, and Parlor Configuration.

Free Stall Dairy Housing Configurations																	
Housing size	Milk cows	Side-Opening				Herringbone										Polygon	
		Double				Double										24	32
		3-1	3-2	4-1	4-2	5		8		10		12	16				
		Auto	Auto	Auto	Auto	Swing	Conv.	Swing	Conv.	Auto	Conv.	Auto	Auto	Split	Auto	Auto	
-----dollars-----																	
80	320	0	0	0	0	10128	10191	0	0	0	0	0	0	0	0	0	
80	400	12937	12873	13113	13049	12511	12574	12862	13070	13541	0	0	0	0	0	0	
80	480	14563	14499	14739	14675	0	0	14888	14695	15167	0	0	0	0	0	0	
80	560	16270	16206	16446	16382	0	0	16195	16463	16874	0	0	0	0	0	0	
80	640	6930	6930	6930	6930	0	0	6930	6930	6930	0	0	0	0	0	0	
100	300	0	0	0	0	9738	10001	0	0	0	0	0	0	0	0	0	
100	400	12391	12288	12566	12464	11948	12011	0	0	0	0	0	0	0	0	0	
100	500	15366	15263	15541	15439	0	0	0	0	0	0	16194	0	0	0	0	
100	600	6577	6577	17676	17574	0	0	0	0	0	17732	18329	0	0	0	0	
100	700	0	0	7620	7620	0	0	0	0	0	20468	7620	0	0	0	0	
100	800	0	0	0	0	0	0	0	0	0	22545	23142	0	0	0	0	
100	900	0	0	0	0	0	0	0	0	0	25556	9706	0	0	0	0	
120	360	11879	11741	0	0	11429	11493	0	0	0	0	0	0	0	0	0	
120	480	14275	14137	14450	14314	0	0	14184	14392	14864	0	0	0	0	0	0	
120	600	6577	6577	18145	18008	0	0	17879	18087	18559	18196	18793	19954	20436	0	0	
120	720	0	0	0	0	0	0	7797	7797	7797	21330	7797	22361	22842	23109	23653	
120	840	0	0	0	0	0	0	0	0	0	23973	9175	25004	25486	0	0	
120	960	0	0	0	0	0	0	0	0	0	0	0	0	27876	28158	28701	
Dry Lot Dairy Housing Configurations																	
100	300	0	0	0	0	7743	7806	0	0	0	0	0	0	0	0	0	
100	400	9613	9494	9789	9670	9386	9449	0	0	0	0	0	0	0	0	0	
100	500	11438	11319	11613	11495	0	0	0	0	0	0	12259	0	0	0	0	
100	600	6577	6577	13168	13049	0	0	0	0	0	13216	13813	0	0	0	0	
100	700	0	0	7620	7620	0	0	0	0	0	15398	7620	0	0	0	0	
100	800	0	0	0	0	0	0	0	0	0	16915	17512	0	0	0	0	
100	900	0	0	0	0	0	0	0	0	0	18713	9706	0	0	0	0	
120	360	9161	9012	0	0	8709	8772	0	0	0	0	0	0	0	0	0	
120	480	10859	10710	11034	10886	0	0	10769	10977	11448	0	0	0	0	0	0	
120	600	6577	6577	13322	13174	0	0	13056	13264	13735	13373	13970	15131	15613	0	0	
120	720	0	0	0	0	0	0	7797	7797	7797	15779	7797	16809	17291	17580	18135	
120	840	0	0	0	0	0	0	0	0	0	17724	9175	18754	19236	0	0	
120	960	0	0	0	0	0	0	0	0	0	0	0	0	20955	21243	21798	

Source: Derived from Appendix Tables B-1 through B-4.

APPENDIX C

Dairy Waste Characterization

Manure Characterization

Animal waste characteristics are functions of many factors. Animal breed, sex, age, size, and activity are predominant physiological factors affecting waste properties (Taiganides and Hazen, 1966; Loehr, 1968; Loehr, 1974; Miner, 1975; among others). Together these physiological factors help determine feed conversion efficiency. But by far the most important factor affecting manure characteristics is the quantity and composition of feed ration. Total manure production and chemical and physical properties are functions of feed palatability and digestibility. However, most research in this area has been focused on the influence of ration fiber content on manure properties. To the author's knowledge, no research has been addressed to the affect of ration nutritional analysis on manure properties.

Berry (1966) and Loehr (1968) among others, point out that manure characteristics differ among animal groups. When making inferences from biological and physical properties of manure, care must be taken not to assume data for one species represents, or are comparable to that of another species. Jefferey et al. (1963) found beef cattle manure to be more biodegradable than dairy cow manure. This conclusion is attributed to the difference between the high concentrate ration fed to beef cattle and the high roughage content of dairy cattle rations.

The dairy waste characterization presented in Appendix Table C-1 is developed from a review of literature and is not derived from analysis of manure in the Chino area. Rather, the physiological nature of cows in the Chino area and typical feeding programs were taken into consideration along with the ranges found in reported literature.^{1/} Design values reported in Table C-1 were verified by a group of experts familiar with the Chino dairy waste situation.

Dairy manure production reported in the literature averages about 85 pounds per cow per day. However, a "Chino cow" averages 1,400 pounds in weight, considerably heavier than the national average and slightly heavier than the state average. The design value of 110 pounds reflects these differences. Heavy feeding programs of 40 to 45 pounds dry matter per day and average digestibility of about 68 percent is consistent with approximately 14 pounds of total solids defecated. High concentrate rations fed for maximum production yield about 11.9 pounds of volatile solids.

Fresh manure is subject to rapid change in physical and chemical properties almost immediately after deposition. The degree of transformation is contingent upon widely varied operating or management practices, i.e., frequency of cleaning confinements areas, type of surface on which manure accumulates, etc. Environmental conditions such as rain and temperature are also critical determinants of eventual physical and chemical properties of manure. For example, in the semi-arid climate of the Chino

^{1/} The wide ranges reported in the literature document the inability to generalize waste characteristics.

Appendix Table C-1. Generalized Daily Waste Production and Characteristics for Dairy Cattle in the Chino Area.^{a/}

Item	Range	Design value
Total net manure, pound	73-147	110.0000
Feeds, pound	40-75	70.0000
Urine, pound	30-45	40.0000
Moisture content, percent	80-90	87.3000
Density, pound per cubic foot	60-63	62.0000
Total solids, pound	10-16	14.0000
Volatile solids, pound	8.5-14	11.9000
Fixed solids, pound	1-3	2.1000
Volatile solids, percent	82-90	85.0000
BOD ₅ , pound	1.8-2.6	2.2000
COD, pound	8-16	12.5000
Nitrogen (total), pound	0.45-0.6	0.5000
NH ₃ -N, pound	0.25-0.35	0.3000
Org-N, pound	0.15-0.25	0.2000
Phosphorus, pound	0.08-0.12	0.1000
Potassium, pound	0.3-0.5	0.4500
Sulfur, pound	0.03-0.05	0.0400
Calcium, pound	0.19-0.28	0.2200
Iron, pound	---	0.0400
Magnesium, pound	0.07-0.10	0.0900
Zinc, pound	---	0.0140
Boron, pound	---	0.0014
Copper, pound	---	0.0005

^{a/} Based on an animal weight of 1,400 pounds.

Source: See text.

production region natural drying is quite pronounced. Containment of fresh manure on concrete, however, inhibits drying. Alternatively, manure deposited in dry lot corrals is subject to rapid drying and subsequent volume and weight reduction. In addition to changes in moisture content, nutrient losses occur from natural biological processes and leaching.^{1/}

Waste Water Characterization

Waste water is generated in the refrigeration, cow washing, and parlor cleaning activities. Chang (1974), in a report submitted to the California State Water Resources Control Board, characterizes the physical and chemical properties of the liquid waste stream. Twenty-five dairies in the Chino-Corona dairy area were sampled to determine the quality degradation of water used in cow washing and equipment cleaning. Comparison of initial water quality and dairy wash water quality is presented in Appendix Table C-2. The quality degradation experienced is largely due to deposition of approximately 10 percent of the manure in the wash-up and parlor area. Per capita water use is the principal factor determining the ultimate effluent quality. Dilution of a relatively constant amount of manure deposited in the wash-up and parlor areas occurs with greater water usage. Although dairy water utilization in the Chino area varies from 25 to 100 gallons per cow per day, average use total approximately 47 gallons per day (A. A. Webb, 1974 and private conversations with Andrew Chang and Gordon Anderson).

^{1/} Sun dried corral scrapings of about 30 percent moisture content average 20 pounds per cow per day.

Appendix Table C-2. Change of Physical and Chemical Characteristics of Dairy Wash Water.

Parameter ^{a/}	Before Wash		After Wash	
	Average	Range	Average ^{b/}	Range
Total Solids (%)	0.05	0.01-0.06	0.38	0.17-0.67
Electrical Conductivity (mmho/cm)	0.79	0.28-2.35	2.53	1.04-4.39
pH	7.6	7.2-8.6	7.9	6.1-8.8
Chemical Oxygen Demand	6.8	0-26.0	3,323.0	114.0-7,454.0
Total Nitrogen	2.90	0-34.0	160.3	40.0-301.8
NH ₄ ⁺ -N	0.48	0-10.8	29.2	4-101.8
K ⁺	4.66	0-5.0	184.5	28-420.0
Na ⁺	41.2	22.0-106.0	95.7	42.0-272.0
Mg ⁺⁺	19.8	1.6-50.0	40.4	21.0-80.0
Ca ⁺⁺	94.5	38.0-330.0	150.6	73.0-340.0
Cl ⁻	49.9	5.7-175.0	154.7	62.6-297.0
NO ₃ ⁻ -N	8.6	0-44.6	9.00	0.7-40.3
HCO ₃ ⁻	219.2	121.0-414.0	632.2	388.0-1,237.0
SO ₄ ⁼	79.5	28.3-449.8	181.0	70.6-554.8
PO ₄ [≡]	0.04	0-0.27	0.47	0.08-0.83

^{a/} mg/l or otherwise indicated.

^{b/} The "After Wash" parameter averages are based on average water useage per cow of 47 gallons per day. [Private conversation with Chang (1975).]

Source: Chang (1974).

APPENDIX D

Total Costs of Dairying Excluding Waste Management

Appendix Table D-1: Total Annual Cost Ranking of Alternative Dairy Configurations Excluding Waste Management by Herd Size, Housing, and Parlor Configurations.^{a/}

Herd size ^{b/}								
375	400	450	500	500	600	600	625	700
			80 ^{c/}	100 ^{c/}	80 ^{c/}	120 ^{c/}		
Free Stall								
H _{5S} 408,224	H _{5S} 431,056	SO ₃₋₂ 472,127	SO ₃₋₂ 545,282	SO ₃₋₂ 541,817	SO ₃₋₂ 635,766	SO ₃₋₂ 633,614	SO ₃₋₂ 661,191	SO ₃₋₂ 728,347
H _{5C} 408,683	H _{5C} 431,515	SO ₃₋₁ 472,748	SO ₃₋₁ 545,500	SO ₃₋₁ 542,248	SO ₃₋₁ 635,985	SO ₃₋₁ 634,236	SO ₃₋₁ 661,622	SO ₃₋₁ 728,566
		H _{5S} 481,166	SO ₄₋₂ 546,523	SO ₄₋₂ 543,059	SO ₄₋₂ 637,008	SO ₄₋₂ 634,857	SO ₄₋₂ 662,433	SO ₄₋₂ 729,589
		H _{5C} 481,626	SO ₄₋₁ 546,721	SO ₄₋₁ 543,468	SO ₄₋₁ 637,206	SO ₄₋₁ 635,456	SO ₄₋₁ 662,842	SO ₄₋₁ 729,827
			H _{5S} 551,862	H _{5S} 548,514	H _{8A} 640,187	H _{8A} 638,348	H _{10A} 667,270	H _{8A} 732,760
			H _{5C} 552,321	H _{5C} 548,973	H _{8S} 677,154	H _{8S} 675,323		H _{8S} 803,828
					H _{8C} 678,678	H _{8C} 676,848		H _{8C} 805,353
Dry Lot								
H _{5S} 395,969		SO ₃₋₂ 456,561		SO ₃₋₂ 526,286		SO ₃₋₂ 614,589	SO ₃₋₂ 639,097	
H _{5C} 396,428		SO ₃₋₁ 457,241		SO ₃₋₁ 526,805		SO ₃₋₁ 615,268	SO ₃₋₁ 639,615	
		H _{5S} 465,650		SO ₄₋₂ 527,528		SO ₄₋₂ 615,830	SO ₄₋₂ 640,338	
		H _{5C} 466,109		SO ₄₋₁ 528,026		SO ₄₋₁ 616,488	SO ₄₋₁ 640,835	
				H _{5S} 534,249		H _{8A} 619,382	H _{10A} 645,225	
				H _{5C} 534,708		H _{8S} 656,358		
						H _{8C} 657,883		

(continued)

Appendix Table D-1 (continued)

Herd size							
750	750	875	900	1,000	1,050	1,125	1,200
100 ^{c/}	120 ^{c/}						
Free Stall							
SO ₄₋₂ 769,699 SO ₄₋₁ 770,109 H _{10A} 775,221 H _{10C} 862,838	SO ₄₋₂ 772,265 SO ₄₋₁ 772,814 H _{8A} 775,756 H _{10A} 777,266 H _{12A} 781,061 H _{16A} 784,441 H _{8S} 863,310 H _{8C} 864,834 H _{10C} 865,567	H _{10C} 994,752	H _{12A} 925,132 H _{16A} 928,511 P ₂₄ 929,658 P ₃₂ 933,532 H _{10C} 1,022,294	H _{10A} 1,031,977 H _{10C} 1,127,216	H _{12A} 1,084,439 H _{16A} 1,087,819 H _{10C} 1,179,660	H _{10C} 1,255,570	H _{16A} 1,226,221 P ₂₄ 1,227,540 P ₃₂ 1,231,324
Dry Lot							
SO ₄₋₂ 744,442 SO ₄₋₁ 744,940 H _{10A} 750,022 H _{10C} 837,630	SO ₄₋₂ 745,115 SO ₄₋₁ 745,773 H _{8A} 748,666 H _{10A} 750,176 H _{12A} 753,971 H _{16A} 757,303 H _{8S} 836,221 H _{8C} 837,745 H _{10C} 838,477	H _{10C} 966,521	H _{12A} 894,145 H _{16A} 897,525 P ₂₄ 898,792 P ₃₂ 902,731 H _{10C} 991,308	H _{10A} 1,000,700 H _{10C} 1,095,939	H _{12A} 1,049,634 H _{16A} 1,053,015 H _{10C} 1,144,856	H _{10C} 1,217,345	H _{16A} 1,187,762 P ₂₄ 1,189,117 P ₃₂ 1,192,966

a/ Cost estimates exclude waste management costs.

b/ Hired cow chasers are utilized with 1,000 to 1,200 cow herd sizes.

c/ Denotes housing unit design capacity.

Source: See text.

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