SYSTEMS ANALYSIS

OF REGIONAL SOLID WASTE HANDLING

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FOREWORD

Effective solid waste management has been hampered by traditional solutions confined to political boundaries. If ever-increasing quantities of solid wastes are to be collected and disposed of, political entities must cooperate and seek solutions together. The solid waste management activities of one community do affect its neighbors. Possible savings by a cooperative, regional approach to solid waste management are evident. For example, two small communities may be able to operate one sanitary landfill less expensively than each operating alone. Or, one large collection system can be more efficient than several smaller ones.

If communities wish to cooperate in solving their solid waste management problems, the optimal use of their facilities and personnel must be found. Today's complicated solid waste systems suggest an approach that considers all interactions. A system may not be optimized by selecting the best components independently, because interactions between components are very significant. A systems analysis approach can provide a technique by which all components and their interactions are considered, and the total system optimized.

This study develops a systems analysis methodology for regional solid waste management. Although this initial effort is far from comprehensive, it can serve as a model for planners in the application of quantitative techniques for establishing more efficient solid waste systems.

--RICHARD D. VAUGHAN, *Director*
Bureau of Solid Waste Management

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SECTION 1. INTRODUCTION, SUMMARY AND RECOMMENDATIONS

Within the normal activities of a society and its population, waste[1] in a variety of forms is generated. In general the activities of production, distribution and consumption each entails the receipt of material, its transposition in form and/or composition, and movement to some other recipient. It has been demonstrated amply that associated with these activities are streams of waste which over the years have become alarmingly larger and more complex in nature. With the growing severity of the solid waste problem, there has occurred, at least on the part of the Federal Government, a broader awareness of the need for drastic measures, both fiscal and technological, to alleviate the problem. It is problematic whether an appropriate degree of interest, concern and responsibility exists, however, at the most critical levels--the producers of waste and those directly concerned with its proper management.

It is difficult to define what is meant by waste. Broadly stated, waste is a material that its producer does not want (Ref. 2). Although the product may have value to someone (either in its present or in a converted state), if its producer does not ask for reimbursement for its removal it is considered to be waste, and at some stage, will enter a waste handling system, either private or public. The point at which it is discarded is considered to be the beginning of a waste management system. There are operational problems in using this definition, however:

(a) Waste is directly related to the producer and <u>his</u> lack of use for the commodity. Since the material may have either direct or indirect benefits to the community, region, or nation, a useful material may or may not be considered waste, depending on whether the producer's attitude coincides with the public's attitude.

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[1] The word "wastes" is a more accurate term than the singular, because the appropriate reference is usually to one or more wastes in any form - solid, liquid and gaseous - or any combination of them. However for simplicity, the singular form is used in reading for adjectives and adverbs (Ref. 1.)

(b) The mere absence of a purchaser of the "waste" from the producer places the commodity in the "waste category" where it might otherwise be considered valuable. The classification of certain scrap materials as waste or not will fluctuate with the market for those scrap materials.

(c) Producer attitudes and scrap material markets change over time. Thus, changes in such conditions as material usage and availability, general economic factors, location of waste produced to potential users, etc., influences the inclusion or exclusion of commodities from the waste category.

By assuming current waste producer attitudes and current practices with regard to fluctuating markets for scrap materials, an examination of waste management can be made without having to resolve conceptual difficulties arising from these limitations on the strict definition of "waste". In a more general problem context than is appropriate for the current study, the definition of waste would be modified significantly by enlarging the spatial and temporal limitations, relaxing the economic constraints and introducing other variant factors (e.g., material substitutions, new processes, etc.) which could influence the classification of the commodity. It is evident that as the definition of waste is modified, the producers, amount and composition of the commodity would change appreciably.

This study was directed toward development of some methodological first steps at systems analysis of regional solid waste management systems. The scope was regional, and it was sufficient to look toward short- to medium-range problems during these first stages. For these reasons, and since the development of analytical techniques did not depend crucially on the inclusion or exclusion of specific materials from the waste category, the adoption of current techniques and practices is believed to be appropriate for the present study.

1.1 Factors Affecting Growth of the Solid Waste Problem

An exploration of the factors affecting the growth of the solid waste problem would be redundant since this subject has already been treated in the literature (Ref. 3 and 4). Rather, a brief summary of the current and foreseeable trends in the problems associated with solid waste would be helpful in providing a basis for appreciating the importance of deriving an effective solid waste management system.

As mentioned above, virtually all human activities and endeavors produce solid waste. The basic factors affecting the increased amount of solid waste are the increasing population of the United States and its improved standard of living (in an economic sense). Since 1940 the population of the Country increased from 131,613,400 people to an estimated U.S. population in 1967 of approximately 198,608,000. This represents an increase of approximately 51 percent. During the same time period the U.S. Gross National Product increased from 99.7 billion dollars to 789.7 billion dollars, an unadjusted increase of approximately 690 percent or an adjusted increase of 232 percent. The joint effect of these two factors on solid waste production along with decreasing salvage and materials reclamation activities has resulted in an increase in solid waste production from 70 million tons per year to roughly 175 million tons per year (Ref. 5), a 2.5 fold increase or an increase of 3 to 3-1/2 percent per annum. As a further explanation of the significant increase in solid waste, beyond the population and economic growth factors is the impact of industrial and technological changes in terms of the composition of materials utilized in manufacture and reduced price of product. For example, with the reduction of the price of paper products, nonreuseable materials are being substituted for more permanent products (e.g. paper napkins for linen or cotton napkins).

These changes have not only increased the magnitude of the solid waste stream, but have affected its composition as well. In addition to the higher proportion of paper content, the proportion which is biologically degradable is decreasing with the increased use of plastics and metal containers, and the further adoption of the throwaway glass bottle. Furthermore, the substitution of aluminum containers for ones made of steel alloys has increased the proportion of solid wastes which will require extremely long time periods to elapse before they decompose.

Along with a rapidly increasing population over the last twenty-eight years, the United States has experienced a period of intense urbanization. In 1940, 56.5 percent of the total U.S. population lived in areas classified as urban by the Bureau of Census.[2] The urban population growth trend for the years 1950, 1960 and 1970 (est.) are shown in Table 1.

Table 1. URBAN POPULATION GROWTH

Year	Population in Urban Areas (percent)
1950	64.2
1960	69.8
1970	75.1 (est.)

Based on a projected U.S. population of 250 million people in 1980, it is further estimated that 79 percent of this population will reside in urban areas. An examination of the populations residing in rural and urban areas reveals that the size of the rural population remains virtually constant and thus nearly all the population growth is being experienced within the urban areas (Ref. 6).

Thus as more and more of the population resides in the urban areas of the United States there results a greater amount of solid waste produced per square mile. This is the result of increasing population density as well as rapidly increasing solid waste generation per capita. Moreover, the general shortage of unused and available facilities for individuals residing in urban areas to either temporarily or permanently store unused materials forces a greater proportion of such materials into the solid waste stream. This results in the collection of greater amounts per capita than is required

[2] "Urban populations include all persons living in incorporated or unincorporated communities of 2,500 population or more, or in densely settled urban fringe around cities of 50,000 inhabitants or more." 1960 definition from Business Fact Book 1963, Part 2, Population and Housing, State of New York Department of Commerce.

in rural regions as well as making more frequent collection necessary. The increase in concentration of waste production introduces the following problems when developing effective and economic long-range waste handling plans:

(a) Local governments are experiencing a scarcity of land which is available for the disposal of solid waste. Either the available land sources are located at considerable distances from the main contributors to the waste streams or they are dependent on other municipalities for land. The factor of distance adds a significant cost to providing the service to the community whereas the factor of dependency introduces significant uncertainty for long-term uninterrupted operations (the San Francisco-Brisbane situation is an excellent case in point).

(b) The increase in population density has the affect of reducing the number of options available to the solid waste managers of individual municipalities in the processing and disposal of the community's solid waste. This reduction of available options is closely tied to the limitation of readily accessible land and the proximity of the population to the waste processing and disposal operations and their characteristics, which are typically considered objectionable by the public.

Of equal importance to such quantifiable factors as numbers of people, population distribution, economic growth indicators, and land use and its availability in discussion the factors associated with the growing solid waste problem are the attitudes of people toward their environment. The increasing amount of information and publicity concerning environmental pollution is evidence of increased interest and action by community leaders with regard to environmental appearance. This may be taken as some indication that people are increasingly dissatisfied with having amenities and services provided on a marginal basis. These changing attitudes and demands have found expression in such Federal programs as the Demonstration Cities and Urban Development Act of 1966 (to improve the quality of urban life), the Highway Beautification Act (to improve the appearance of the country-side), the Solid Waste Disposal Act of 1965 as well as a variety of federal and state-supported urban renewal acts and projects.

With these changing attitudes, people are no longer willing to tolerate a variety of unsightly and/or potentially health-menacing practices associated with solid waste handling. Open dumps, and dumps with open burning, although still plentiful throughout the United Stated, are slowly being eliminated; unsanitary landfill practices are being eliminated due to health ordinances and statutes; open and/or uncovered collection vehicles are being replaced. The need for substitutes for these practices and facilities amounts to a general requirement for increased system performance. Associated with the requirement for improved performance and greater benefits is the cost incurred in achieving these higher levels of operation. It is the explicit recognition and determination of the increased costs and the benefits obtained which must be available to the population and their decision makers when assessing changes to the methods of handling solid waste.

In 1962, the American Public Works Association pointed out that the annual public outlay for refuse collection and disposal services of over $1.5 billion is exceeded only by expenditures for schools and roads (Ref. 7). The storage, collection, transportation, processing and disposal of solid waste is one of the major budget items within urban areas. In addition to the expenditures by local governmental agencies, the editors of Refuse Removal Journal (Ref. 8) have estimated that the annual expenditures of the private sanitation industry are over $1.3 billion. Thus with increasing labor and equipment costs and the larger amounts of solid waste being collected and disposed, it is estimated that the total direct cost is somewhat in excess of $3 billion annually.

Beyond the direct costs of solid waste management are those indirect costs associated with the deleterious effects derived from solid waste and its handling. Although it is not possible to establish a cost budget relating the effects to a monetary measure, in part because of the subjective components associated with certain effects (odors, unsightliness, flies, etc.) and the lack of basic knowledge pertaining to cause-effects (e.g., relationships of respiratory diseases and particulate matter), there are a variety of indirect costs which are measurable. Among these costs are those related to additional cleaning and/or painting of household furnishings, streets, houses, cars, etc.; losses in tax revenues; losses in income due to illness, accidents and diseases; degradation in agricultural quality and crop yields; and deterioration of national resources. Although no systematic and successful estimate of the indirect costs has been achieved, it is believed that the estimate derived would exceed the direct costs associated with solid waste handling. If this belief is correct, the usefulness and validity of cost benefit analyses which are restricted to direct costs exclusively must be viewed as providing only partial guidance and in certain instances may be highly misleading since the deleterious effects associated with different methods of collection, processing and disposal vary significantly.

1.2 The Solid Waste Disposal Act of 1965

In recognition of the current seriousness of the threat to the environment and the growing concerns and changing attitudes of the population, the Federal government has made a commitment to support and assist in a coordinated national effort to alleviate solid waste problems. This commitment is embodied in Title II of Public Law 89-272, the Solid Waste Disposal Act, which was signed into law on October 20, 1965. In summary, the Act authorizes specific action in six areas of need (Ref. 9): (1) grant support for local and state projects to demonstrate new and improved waste disposal technology; (2) grant support for the development of area-wide solid waste management systems to end fragmentation of responsibilities among small communities; (3) grant support for State surveys of solid waste handling needs and the development of statewide plans for meeting needs; (4) research, both direct and grant-supported, to establish the basis for new approaches to solid waste handling; (5) training programs, both direct and grant-supported, to alleviate critical shortages of trained personnel; (6) technical assistance to local and state governments with solid waste problems. The Act commits the Federal government to the role of supporting partner with local and state agencies in solving solid waste problems. Primary responsibility for solid waste handling and carrying out programs for improved practices remains at the local and state levels.

The actions authorized by the Act recognize that the development of acceptable solid waste handling solutions transcends the economic and technological capabilities of local communities. Additionally, because the effects of solid waste handling practices are in many instances experienced beyond the local community, the desirability of establishing regional solid waste management districts is suggested. Rather than having the Federal government establish solid waste regions as is being done for Air Quality Regions, the responsibility for improving solid waste handling practices is being left with the local community. The Federal government views its role in the area of solid waste as providing fiscal and technical support.

Among the factors which appear to motivate the decision to maintain the responsibility for carrying out programs and improvements at the state and local levels are

(a) The options available and/or suitable to communities vary considerably.

(b) The political and population receptivity to solving their solid waste problems, and the quality of service desired, are markedly different.

Although the broad definition of the solid waste handling problem may be specified, the detailed examinations and analyses to be performed and the feasible solution set to be derived must be related to characteristics and needs of the individual region, if they are to be appropriate and useful.

1.3 Objectives of Solid Waste Management Research

The objectives of this study are to define and perform a systems analysis of the solid waste handling problems confronting regional decision makers. As a systems analysis investigation, the functions of solid waste handling -- collection, transportation, processing and disposal must be considered as integrated and coordinated activities rather than individual and independent operations. Additionally, the interrelationships between solid waste handling and the handling of liquid and gaseous wastes must be recognized since, as has been shown by others, numerous aspects of the solid waste problems could be eliminated readily by appropriate transformations of solid waste into liquid or gaseous waste. Thus the proper understanding and actions taken relative to solid waste management should be made with full cognizance of their impacts on the other waste streams and their effects on total environmental pollution.

A question of great significance in solid waste management is the following -- what is or are the desired objectives of solid waste management? At the most simplistic level, the objective is to relocate the solid waste to an area which is unobjectionable to the population, and is performed at the lowest cost. Another stated objective is to transform solid waste into inert material which does not pollute the environment and to accomplish this transformation in a manner which is acceptable to the standards (e.g., sensory, aesthetic) prescribed by the population. Still another objective is to reclaim and reuse, as much as possible, the solid waste materials which are currently destroyed. At present there does not appear to be an objective or compatible set of objectives which has been made explicit and which is useable at various decision making levels concerned with solid waste management. Although it is understood that the objective of solid waste management is not invariant with time, it is important to make explicit the goals so as to assist the planners, and to allow for their review periodically and determine whether or not they are still relevant.

Consider for the moment that a study of solid waste handling had been initiated in 1930 with the objective of providing assistance for solid waste planning out to the year 1965. Beyond the fact that the current concerns relative to solid waste handling were virtually nonexistent at that time, except for a limited number of sanitarians, the examination would have in all probability, been addressed to a localized municipal area and to one or more handling functions which would have been treated as independent activities. But of much greater importance, those planners, concerned with making projections of solid waste generation and handling requirements, were confronted with having to make assumptions pertaining to the following factors (similar to those facing current investigators):

(a) Size of population residing in municipality.

(b) Rate of change in urbanization migration.

(c) Introduction of new residential housing forms and associated population densities.

(d) Increased generation of refuse per capita as reflected by changes in income levels and standards of living.

(e) Economic projections of commercial and industrial expansion and modification of products and processes and their associated solid waste generation.

(f) Changes in the composition of refuse -- anticipation of reduction in quantity of ash; increase of paper, bottles, cans; introduction of plastics, etc.

(g) Reduction and/or disappearance of available land for solid waste processing and disposal.

(h) Modification of attitudes and changes in legislation with respect to acceptable levels of solid waste handling practices.

This list of factors could be expanded many times but it is apparent that most, if not all, of the above could not have been anticipated with any reasonable degree of accuracy for the purposes of the proper planning of solid waste facilities. Along with demographic, economic and land use factors, projections pertaining to technological innovations and modifications had to be considered. Here the planners were more successful since although technological improvements had been introduced over this 30-35 year period, the basic processes and options available have remained fairly constant. Although materials handling and transport equipment have improved significantly, and processing and disposal practices have changed, the modifications can be characterized by greater efficiency rather than by technological innovation. In general, the outputs of these planners were a single projection of the future which was made using rather crude estimating and statistical techniques, and a series of recommendations for individual processes and facilities.

Now consider the present time, and the approaches being utilized by investigators who are attempting to benefit from some of the shortcomings of past studies in providing planning tools and assistance to decision makers. Three basic considerations are starting to be explicitly introduced into these investigations:

(1) Waste management, be it solid, liquid or gaseous, is being examined on a regional basis; the size and definition of the region is dependent on the particular waste and its associated pollution effects and the geographical location of the area being studied.

(2) Recognition is given to the interrelationships among the waste streams (solid, liquid and gaseous) in developing solutions to the solid waste handling problems.

(3) Solid waste handling, involving the interrelated functions of collection, transport, processing and disposal, is viewed as a system and is approached using the methods of systems analysis.

Many, if not all, of the factors (a through h above) are still as elusive as they were previously although the statistical techniques available for projecting are more sophisticated. The systems analyst with the assistance of regional planners, demographers, and economists makes a series of plausible assumptions concerning the future and develops projections for each assumption or set of assumptions. This approach to forecasting and projecting results in a variety of projections concerning the future. Now, given a large number of candidate alternative solid waste systems, evaluations can be performed utilizing all the projections derived, and results, in terms of cost and performance measures, can be obtained for each set of projections. The final step in this analysis process is the performance of sensitivity analyses, that is, the determination of the quantitative sensitivity of the measured system outputs to the indivdiual projections made. It is the presentation of these forms of results to the decision makers which provides them with an appreciation of the relationships among the assumptions, projections, system and outputs.

The role and responsibility of the analyst are to provide a spectrum of choices, whereas the responsibility of those involved in decision making is to select those assumptions and conditions which, in their judgment and authority, most closely represent the interests and needs of the region. In view of the uncertainties associated with the above factors, those candidate systems whose performance measures and cost are within acceptable limits and are not highly sensitive to changes in the projected factors represent desirable candidates for selection. In view of these analytical requirements, the main objectives of this study were to define the considerations which should be introduced into the examination of regional solid waste management, to formulate a comprehensive solid waste system evaluation structure, and to develop some detailed mathematical models for assisting in the decision-making process.

1.4 Summary

Directed toward the objectives outlined in Section 1.3, examination of many of the factors and trends leading to the current crises in solid waste management and overall environmental pollution was carried out, leading to the formulation of an overall solid waste system evaluation structure and the development of some mathematical models. This effort represents a start toward more comprehensive systems analyses with regard to solid waste systems. It is expected that these contributions will eventually lead to more objective and quantitative bases for establishing solid waste system requirements for planners and policy decision makers during the next generation. Even in its present form, the facility selection model of Section 4 represents a tool of more than modest usefulness.

A literature search and consideration of specific problem types and their manifestations within the Buffalo SMSA permitted the examination described in Section 2 of measures of effectiveness. It was concluded that along with measures of pollutants and costs, some measure of the land useage associated with the solid waste disposal system offered a promising possibility as a measure of effectiveness. This is not necessarily the only useful measure of effectiveness in addition to pollutants; but before attempting to work with other measures, this one was adopted as the initial trial.

This approach was utilized in developing the evaluation model structure of Section 3. The process of developing the model structure was a necessary step in providing an orderly means of considering different systems analysis models and comparing them with regard to scope, overlap or complementarity, and compatibility. As a result of this effort, a comprehensive list of data items required for solid waste system analysis is given, together with a list of required submodels and a description of their functions. This is not to say that system analysis cannot be carried on without all the items listed or all the submodels; it does say that all items are present at least in some implicit form in any systems analysis; if an item is not explicit in the model it is because it is being substituted for by some simplification device or it is being held constant by assumption.

As part of the evaluation model structure a conceptual screen and screening procedure was developed which permits a systematic approach to the examination of candidate systems to determine whether they meet the acceptance levels of performance prescribed by or imposed on the region. The screening procedure is useful in rejecting candidate systems which cannot meet the standards prior to the more extensive and expensive procedure of system evaluation as described in Section 3.

As a result of the studies described in Section 3, it was decided that development of a model as comprehensive as the entire evaluation structure was inappropriate for this limited level of effort and short time duration study. It was decided instead to concentrate on a more limited modeling effort which, (a) could be completed in a relatively short time period, (b) would require data that was already available from the Buffalo SMSA and, (c) could be put to use in actual regional decision-making. A static model, with a manageable level of detail, for choosing among alternative facilities and making assignments of source areas to the facilities chosen was developed. This model was useful in the following respects:

(1) Since the model was computerized, large numbers of alternative specific system configurations could be compared;

(2) Through series of runs under systematically varied input parameters, the characteristics of economically desirable systems could be defined, thus allowing design of a system configuration toward those characteristics;

(3) The minimum cost yielded by the model for any set of input parameters and possible choices of facilities can be used as a normative value. Thus a system configuration which violates the facility choices and service area assignments corresponding to the minimum cost represents an additional cost which is presumed to pay for the elimination of some undersirable aspect of the minimum cost configuration.

The application of (3) is fundamental to one method of introducing into the analysis the "trading-off" of costs against various levels of deleterious effects (Section 4.4).

The model developed is described in Section 4. The same section contains comments on potential applications of the model and some experience already obtained with the model. The facility selection model leads naturally to a more comprehensive next-stage development which could not be achieved on the present study but which is achievable through further study of scope similar to the present one.

A further major segment of work on this study was the compilation and analysis of data descriptive of the Buffalo SMSA. The results of this work are contained in the various appendices. In particular, estimates of residential and non-residential refuse for all census tracts throughout Erie County were obtained and projected in five-year periods out to the year 2000, and an estimate was derived of the operating cost per mile of Buffalo collection vehicles in spite of the absence of maintenance records and odometer readings.

As part of the examination of solid waste handling operations and planning in the Buffalo SMSA and elsewhere it was observed that an artificial separation was maintained between residential solid waste and solid waste generated at most other sources. The results of a preliminary analysis (Appendix F) demonstrated the economics of scale which could be realized if all waste planning and operations within a region were coordinated and the available land could be utilized more efficiently. Further examinations of this form of coordination appear warranted.

1.5 Recommendations

The recommendations being made are a result of observing and assessing the significant gap currently existing between the knowledge derived from research programs of solid waste techniques and mathematical approaches to solid waste management, and the general level of consulting services available to individual communities, with their apparent limitations (limited support, incomplete data, single forecasts and derivation of a "blueprint" for solving the community's problems). What is strongly lacking is the availability of suitable and useful regional information, and the necessary methodological and evaluative approaches which should be accessible in suitable forms to both the regional planners and the consultants in the solid waste field.

In outline form, a two to three year program is recommended having the above objectives, and which includes the following activities:

1. Provide appropriate projections and forecasting techniques for estimating future residential, commercial and industrial solid waste generation quantities. Included here would be the collection and presentation of data pertaining to waste generation coefficients associated with sources of generation.

2. Establish the form and content of a regional solid waste management information system which contains: (i) necessary time series data on solid waste generation sources (including location, types, quantities and handling practices); (ii) current regional solid waste handling practices relative to collection, transport, processing and disposal, (iii) cost data bank for all solid waste activities.

3. Maintain information on liquid and gaseous waste management practices and interrelating pollution effects with solid waste

handling. This information would include, to the degree possible, the deleterious effects associated with all waste handling and objective measures of these effects.

4. Gather, evaluate and translate the available mathematical models used for operations and planning (e.g. facility location determination), in a form which enables them to be applied by planners and solid waste consultants.

5. Develop an information gathering approach and method of transforming research and development results on new processes and equipments which would allow for their being synthesized and evaluated.

6. Formulate operationally-useful evaluation system models which are applicable under conditions when a large digital computer is available and when only desk calculators or slide rules are available. The evaluation system models would be described in sufficient detail so as to allow for their application without extensive training. These models would be structured in a fashion that permits their being changed, if and when, new or improved submodels become available.

Although the above recommended program will be difficult to accomplish in the form outlined, the value to be derived by the planning and consulting communities as well as some organizations responsible for solid waste operations would be exceptionally high. In brief, having the above capabilities available would permit the planners to perform some preliminary assessments of the region's waste management problems, would enhance the effectiveness of the consultants, and would provide the regional decision makers with a sounder, quantitative basis for selecting from among alternative solid waste candidates.

SECTION 2. SYSTEMS ANALYSIS OF REGIONAL SOLID WASTE MANAGEMENT

> "There is an increasing acceptance of the argument that a systems approach to urban and regional pollution problems has become imperative. The present complexities of environmental problems and the knowledge that, as time goes on, these issues will become even more complex and interrelated makes this conclusion inescapable. The system should be one that can be tailored or adapted to socio-geographic areas (not generally congruent with political subdivisions) of varying sizes and heterogeneity, and can be modified or extended as needs arise. Analyses undertaken for such systems can provide the information required for action today, and will furnish invaluable leads to the research needed to provide the bases for tomorrow's programs" (Ref. 3)

2.1 Introduction

The title of this section, Systems Analysis of Regional Solid Waste Management, incorporates the methodological approach utilized and the spatial extent selected in defining and investigating some of the problems of solid waste handling. No attempt will be made to describe formally the philosophy, methodologies, and techniques of systems analysis since this has been accomplished by many authors. (See R. N. McKean, Efficiency in Government Through Systems Analysis, New York, John Wiley and Sons, 1958, and Charles J. Hitch and Roland N. McKean, The Economics of Defense in the Nuclear Age, New York, Atheneum, 1966.)

The concept of a region has been employed within this study since it is generally accepted that long-term and successful approaches to the problems associated with solid waste handling usually encompass a geographic area which is larger, or at least different from, the traditional political boundaries. Some of the most cogent reasons employed for examining solid wastes on a regional basis are:

(a) Solid waste disposal is a subportion of the waste disposal problem, and solutions to the problems of solid waste are highly interrelated with other waste problems.

(b) The extent of the pollution effects associated with potential solutions of the waste disposal problems transcend, and in virtually all instances, have little relationship to political boundaries.

(c) The set of options available for solving the solid waste handling problems increases as the size of the geographic areas is enlarged. Among the factors supporting this statement are (1) greater available economic resources and opportunities to achieve economies of scale, and (2) the presence of sufficient land resources which can be dedicated to the needs of solid waste disposal.

A variety of studies and surveys, e.g. of the Detroit Region (Ref. 12), Metropolitan Toronto, Northeastern Illinois (Ref. 13), and the Capitol Region of Connecticut (Ref. 14), have suggested the desirability of regional approaches to solid waste management in many areas.

The Buffalo Standard Metropolitan Statistical Area, which consists of the Counties of Erie and Niagara, was selected to serve as the empirical basis for this study. This region represents a viable interrelated economic and planning entity (as defined by the Department of Housing and Urban Development) and contains a variety of community types and land-use patterns. The Buffalo Region was used to suggest problem areas and as a source of data for suggesting relationships, determining the orders of magnitude of various descriptive parameters, and providing inputs to the models developed. As the study progressed, it developed that greatest use was made of data from Erie County, and relatively little from the rest of the SMSA. The attempt, however, was to describe problems in terms of general models which could be applied to both counties in the SMSA, the SMSA as a whole, or in fact to other regions in the United States.

The systems analysis effort of this study and the related efforts of data collection, analysis and model building related to regional solid waste management are predicated upon a conceptualization of a regional environmental control and waste management decision-making structure and on the objectives of a regional solid waste management system within the structure. One cannot claim that the detailed decision-making structure of any particular region actually does follow the clean organizational lines of the conceptual structure. In particular, except when described in the broadest terms the decision-making bodies within Erie and Niagara Countries do not fall into this pattern. What is postulated, however, is that representation of regional decision-making as if it were structured according to the conceptualization is useful in indicating the types and levels of decisions which must be made (whatever the detailed structure) and the information requirements for those decisions. The selection of measures of waste management system effectiveness and the measurement of performance of alternative solid waste handling systems for the region, are based upon this concept of the regional system.

2.2 Solid Waste Management as a Subsystem of a Regional Waste Management System

In the performance of a systems analysis, the measures of system effectiveness which are selected should be in quantifiable terms which relate to the function or service being performed in as direct a manner as possible. In the context of regional solid waste management there are a number of choices; examples of effectiveness measures may be related to the following attributes:

- Pest and Vector Propagation
- Other Physically Disagreeable or Harmful Effects
- Safety Hazards
- Incidence of Disease

- Convenience to the Waste Producer
- Adaptability to Statutory or Other Changes in Requirements
- System Reliability
- Production of Saleable By-products
- Salvage of Resources for Return to the Economy
- Conservation of Land Resources

The appropriate form and level of importance to be given these measures is discussed later within this section. However it is recognized that the performance of any candidate system could be determined on the bases of measurements of the above factors providing that the system operation is not objectionable in terms of gaseous and liquid wastes, and associated air and water pollution standards. In other words, two systems would not be judged equivalent if they perform similarly with regard to the factors given above, yet (for example) one introduces large quantities of pollutants into the air. As another example, a system which incorporates the widespread use of refuse grinders and employs the sewer for refuse disposal could provide a high level of land conservation but at the cost of a drastically worsened sewage disposal problem and a potentially serious water pollution problem.

As has been well recognized and documented, solid waste handling problems are intricately bound up with many other aspects of waste handling and environmental pollution. These relationships result in difficulties in studying solid waste management if the approach utilized is to consider air and water pollution simply as effects of the solid waste management system. Clearly, air and water pollution are measures of effectiveness appropriate to the entire regional environmental control and waste management system, of which the solid waste management system is only one portion. Thus, operating within the solid waste management system alone, it is not possible to optimize regional waste (i.e., solid, liquid, gaseous) management. From this statement, the following two conclusions may be drawn:

(a) If the solid waste management system is studied separately from the remainder of the regional waste management system, it should be done by treating solid waste management as a subsystem. Such as, those properties or performance measures which affect other portions of the overall system would be measured and provided as inputs to analyses of tradeoffs among the various subsystems.

(b) The measures of effectiveness and performance of the solid waste management subsystem per se should be based on the subsystem function exclusively, although their interpretation will necessarily be relative to the measures related to the other subsystems.

The designer of the solid waste management system is in some respects in a similar position to the designer of the military weapon system who needs a definition of effectiveness to evaluate alternative concepts. In a general sense, the effectiveness of the weapon system is its contribution, as part of the entire arsenal of the nation's weapons, to the military strength of the country. This definition is too general to be useful and almost impossible to measure quantitatively. The useful measures of effectiveness are more likely to be described in terms of expected kills, increased size of enemy force required to oppose the system, etc. The principle of selection of effectiveness measures can be summarized as follows:

> The effectiveness measures should be appropriate to the decision-making level employing the measure; i.e., effectiveness should measure the results of the decision being made and not the results of choices or actions beyond the range of responsibility of the decision-maker. On the other hand, the measures should be sufficiently comprehensive so as to be of use to the decision-maker at the next higher level.

In general, planning decisions with regard to solid waste management are viewed as constituting a functional responsibility within the regional planning decision-making complex. For example, within Erie County, the Commissioner of Planning and his staff play a major role in developing solid waste management concepts. The various responsibilities within the decision-making complex form a hierarchy corresponding to the functions within the regional political structure of the officials involved in making planning-decisions. A simplified pattern of regional planning-decision making is shown on Fig. 1 The entire planning hierarchy is not shown but only that portion which includes solid waste management planning has been expanded to illustrate various decision-making levels.

Within the hierarchy, the highest decision-making level in regional planning is viewed as involving interactions among economic development, land use, transportation, environmental control and waste management as well as several other areas not shown. Subsumed under the environmental control and waste management area, decisions are made involving interactions among the problem areas dealing with liquid wastes, gaseous wastes and solid wastes. Simultaneously, decision-making activity is carried on within the subordinate problem areas. The activity is a continuing iterative process, with results at the higher level constraining the analyses on the lower level while results within the lower level problem areas impose input changes on evaluations at the higher level. Decisions at the higher level do not necessarily supercede those taken at the lower level; the "levels" relate to the detail of the information used in the system evaluation and decision-making activity, rather than to political power.

The principle stated above,related to the solid waste management problem,indicates that decisions regarding the water and air pollution aspects of solid waste management are in effect decisions taken at the next higher level - environmental control and waste management. Thus systems analyses with regard to solid waste management should be structured so as to assist the decision-maker responsible for environmental control and waste management -- a decision-making level responsible for waste management in its totality.

The information flow relating to that decision-making level is illustrated in Figure 2. The structure consists of three parallel subsystems: one involving gaseous waste management and air pollution, one involving liquid waste management and water pollution, and the third involving solid waste management and land pollution. The three subsystems are completely interconnected, which means that the problem confronting each subsystem results from the total environmental situation (i.e., the region's total waste and

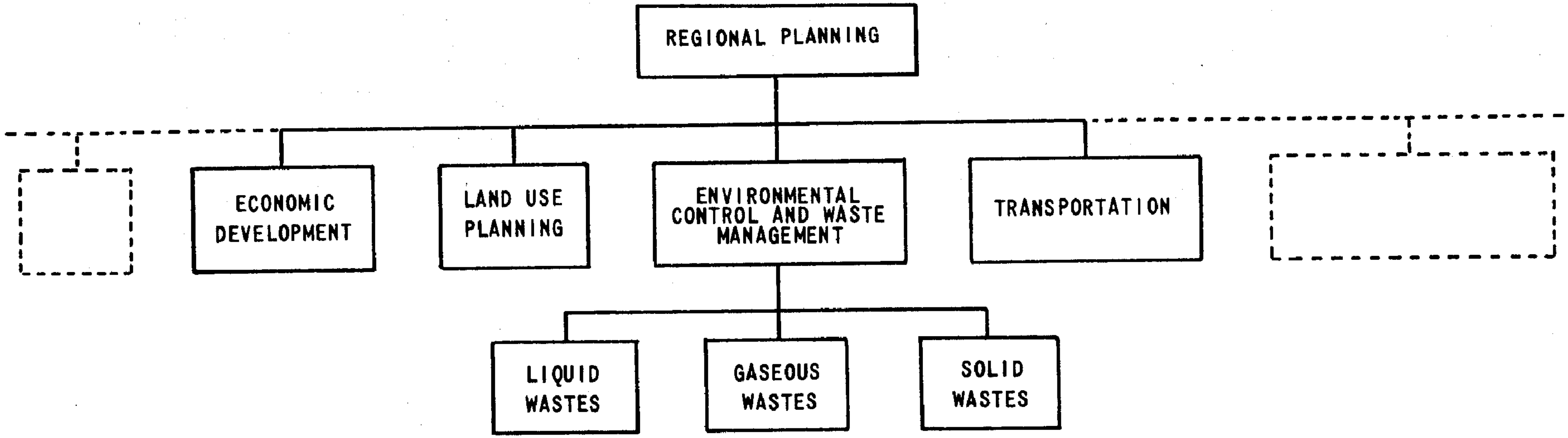

Figure 1 SIMPLIFIED REGIONAL PLANNING-DECISION MAKING HIERARCHY

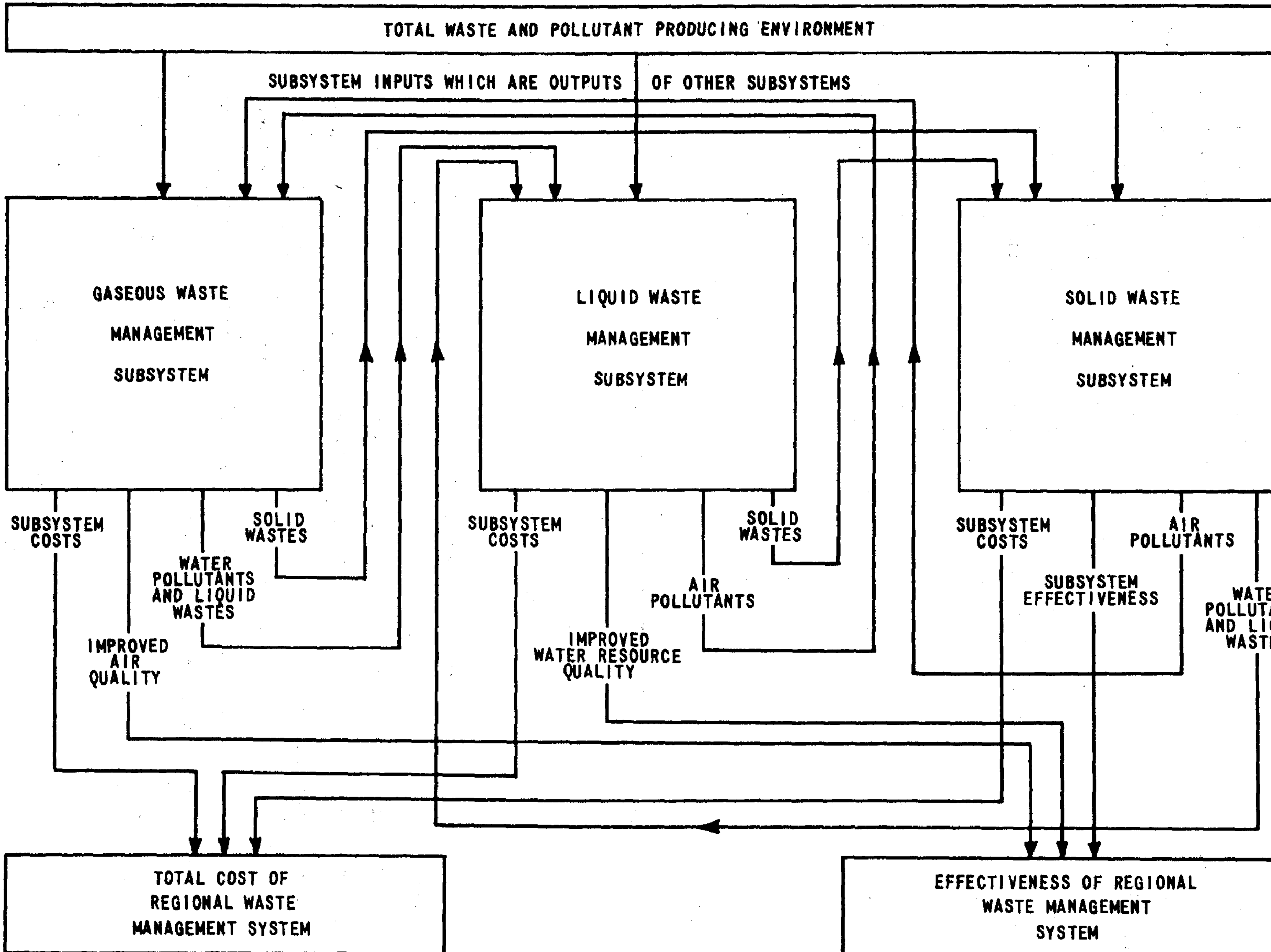

Figure 2 TOTAL REGIONAL WASTE MANAGEMENT AND POLLUTION CONTROL SYSTEM

pollutant producing activities, excepting pollution control and waste removal activities) and from side effects of waste or pollution management activities within the other two subsystems. For example, the input to the liquid waste management subsystem results from all liquid pollutant-producing activities of the household, industrial, and public sectors of the region. Included in this input are the introduction of solid waste grindings into the sewer system which provides a partial relief to the solid waste management subsystem and other products of solid waste disposal operations such as waste waters resulting from incinerator residue quenching operations, and leachants into the ground waters resulting from landfill operations.

At the total waste management system level, the requirements for information regarding any candidate subsystem consist of the following:

(a) Amount of pollution of interest to the given subsystem which remains after the waste has gone through the subsystem;

(b) Direct costs of the subsystem;

(c) Pollutant outputs by the subsystem which are of interest to the other subsystems.

If, for each of the three subsystems, the above outputs are established as a function of the input amounts of waste and pollutants received (as a result of water management or pollution control activities associated with the other subsystems), the decision-maker of the total waste management system has the essential information necessary for decisions regarding the overall system. Given any combination of postulated subsystems, and assuming appropriate analytical models, the following properties of the overall system can be investigated:

(1) Compatibility and Balance

By virtue of the output pollutant and waste data associated with the individual subsystems, a determination can be made of each subsystem's capability to handle all the wastes or pollution conveyed to its part of the system. For example, if the liquid waste exceeds the design capacity of the liquid waste subsystem, then these subsystems, when examined jointly, are incompatible. Subsystems which can function together in the sense that no capacity violations or exceedances of technological capabilities would result are compatible. On the other hand, a compatible system is conceivable in which there are subsubsystems whose entire capacity or capability cannot be utilized, thus representing an inefficient use of resources. A desirable system is one in which there is a state of balance; each subsystem is just large enough and has just enough technological capability to handle all waste and/or pollutant inputs to it from the general environment as well as from outputs from the other subsystems. Since facilities must be planned to serve over substantial lengths of time over which the quantities of wastes of various types will change, the concept of balance must admit some unused capacity over the lifetimes of the facilities to admit performance over the entire range of projected input quantities.

(2) Total Direct Costs

Since one of the descriptors of any subsystem is its direct costs, the total costs of any balanced system can be determined, as defined above, by the addition of the individual subsystem costs.

(3) Overall System Effectiveness

Each subsystem, in addition to direct costs and information pertaining to waste and pollutant outputs to the other subsystems, has been described with regard to the improved environment resulting from the operation of the subsystem on given input amounts of pollutants and wastes. The aggregation of these data from the three subsystems of any balanced system constitutes the information upon which an evaluation of total waste system effectiveness can be performed. These data represent the amount of pollutants or wastes remaining in the environment.

Having discussed the nature of systems analysis with regard to the total regional waste management and environmental control system, and its relationship with the solid waste subsystem, there remains the question of the nature of system analysis specifically with regard to the solid waste management subsystem. That measures are required of subsystem direct costs, and of quantities of land, water, and air pollutants which are output by the subsystem, have already been indicated. But there are many possible configurations of the subsystem which might appear similar on the basis of these types of measurements alone. In particular, the interactions among the variety of waste sources, of solid waste types, of processing and materials handling techniques, and of operating, management, and regulative bodies, which characterize the complex called the solid waste management subsystem, make choices among subsystem configurations difficult. A set of measures of effectiveness appropriate to choices at this level is required; these measures would be basic to systems analyses devoted to choosing among alternative solid waste management subsystem configurations.

2.3 The Role of Deleterious Effects in Deriving Effectiveness Measures for Solid Waste Management Systems

On possible way to describe the effectiveness of the subsystem concerned with solid waste handling is to measure various deleterious effects, which are to be as small as possible in a "good" system of any given cost. In addition to air and water pollution, with which we have already dealt, commonly mentioned deleterious effects of solid waste and of solid waste handling practices may be grouped as follows[3]:

(a) Pest and Vector Propagation (Flies, Other Insects, Rodents)
(b) Other Physically Disagreeable or Harmful Effects (Toxicity, Odor, Unsightliness, Interference with Wild Life)
(c) Safety Hazards
(d) Incidence of Disease (Human Disease, Animal Disease, Plant Disease and Crop Damage)

Certainly an ideal system for managing solid wastes would have all these effects at a minimum level. Moreover, a concern for most of these factors in combination is at the root of the reason for waste removal (beyond the problem of having insufficient storage capacity); in other words waste is nuisance material which must be removed from its source locations fundamentally because of most of these factors.

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[3] A comprehensive literature survey of the health aspects or disease relationships of solid wastes as well as the injury and safety considerations associated with solid waste handling is contained in Ref. 10.

It does not appear that a measure of effectiveness based heavily on these deleterious effects would be of greatest assistance in making decisions relative to solid wast handling systems. There are several reasons to support this contention. First, if many factors are combined in a measure of effectiveness, there is a danger that the measure will be insensitive to any individual factor. A desire to be all-inclusive can result in de-emphasis, for example, on the importance of the scarcity of available land in many areas. In other words, from the point of view of decision-making with regard to subsystem planning, it is desirable to attempt to isolate a small number of items which appear to be intricately involved in the tradeoff process incident to subsystem design and which are basic to solid waste management problems as they occur in the real world. As will be seen from subsequent discussion, there are other measures potentially more useful for decision-making in the face of the dilemmas typically troubling the regional planner than the deleterious effects listed.

A second, and more fundamental, reason for desiring to emphasize factors other than the deleterious effects is that these effects are not "traded-off" during subsystem design. Instead, these effects are recognized, perhaps implicitly, by keeping them within acceptable levels and paying the costs. Conceptually, any system planned with levels higher than these acceptance levels has zero effectiveness and is not to be considered. The concept of acceptance levels and their use in screening solid waste handling systems are expanded upon in Appendix E.

For example, there would be a threat of fly and rodent propagation, as well as such other deleterious effects as odor, if a system of non-removal of waste was contemplated. Therefore, a service is performed by any system which removes waste at all, to the degree that the fly and rodent propagation (and other deleterious effects) at the source of waste generation are reduced. This approach is most useful, however, in explaining why removal of waste from the local source within some minimal time is necessary; in other words a statement is given of the necessity for some system which will not give fly and rodent propagation the time and conditions required to become established. In designing the system, however, "trading-off" with regard to various levels of these nuisances plays no operationally-useful role. In the conceptual or design phase of a system no one thinks of allowing a higher level of fly propagation in exchange for a lower rat population. Similarly, there is no implication that a system with a relatively low rate of fly propagation is significantly worse than a system accompanied by even less flies; nor is there any implication that a system which allows rodents to propagate is any better than a second system which allows even more to propagate. In other words, the realistic decisions made on the level of broadest impact on the system design assume that there is a maximum level of nuisances and pests which will not be exceeded. Any system which exceeds these levels is unacceptable, no matter what its other properties. Conversely, any system in which these effects appear at below maximum acceptable levels is not considered better for that reason, except in the rare case where two systems are equivalent in all other respects. In summary it can be stated that a low rating with regard to one deleterious effect cannot be offset by a particularly high rating with regard to another.

Therefore, pest and vector propagation, other physically disagreeable or harmful effects, and safety hazards to the public are introduced into our analyses as side conditions and are not part of a primary measure of system effectiveness. Any system which does not meet minimal acceptable levels with respect to these factors are assigned zero effectiveness. The study has proceeded under this condition by assuming that the acceptance levels associated with the various standards would, if possible, be specified by either laws and legislation or by subjective/objective positions taken by regional representatives associated with solid waste handling.

While the establishment of public health as the primary measure of social costs would lead to conclusions given, it is not clear that from an economic or land-use point of view one would reach the same conclusion with regard to some of the "other physically disagreeable or harmful effects." Fire hazards are appropriately included among these effects. For example, the unsightliness or odor associated with a waste disposal facility may have a second-order but quantitatively significant effect on the usefulness of land parcels in the vicinity of the facility proper. The possibility of relating the physically disagreeable or harmful effects to the economic and land use measures discussed further on bears further investigation. Experience to date has amply demonstrated that the economic impact on values and uses of land in the vicinity of a disposal facility is primarily a function of public attitudes and good public relations rather than being related exclusively to the presence of the facility.

Safety hazards to the region at large is an effect already mentioned as one to be handled similarly to the "other physically disagreeable or harmful effects." On the other hand, safety hazards to refuse collection, processing and disposal personnel are costs to the system itself rather than social costs and are believed not to have an equivalent place among the measures of effectiveness. To the extent that a given system might be so lethal or dangerous as to be intolerable to the public, a side condition would of course be set to preclude the use of such a system. However, it does not appear that any of the major candidate system types comes so close to falling in this category that it would be worth the trouble to include safety hazards as an explicit side condition. As far as differences in terms of injuries is concerned, these should arise naturally as additional elements within the collection, processing and disposal costs.

The "incidence of disease" effects have not been included since they are functions of more basic effects which are already represented previously. Human disease, for example, is already implicitly incorporated by virtue of the role played within the analysis of the "tradeoffs" with air and water pollution, and by virtue of the controls on pest and vector propagation, toxicity, and safety hazards. In spite of the difficulty in establishing relationships between diseases and waste disposal practices, one might consider adopting the "incidence of disease" effects for explicit treatment, in which case it would be desirable to eliminate the more basic effects correlated with them. For example human disease incidence which is traceable to solid wastes and solid waste management practices depends in part on disease vector propagation. If human diseases were included among the measure of effectiveness, it would be desirable to eliminate vector propagation. However, the latter effect is objectionable for reasons other than disease incidence. As reported by an Aerojet-General Corp. study (Ref. 11), flies and rodents are objectionable far beyond their disease-carrying capability. The same study indicated in general a rather low weighting to the "incidence of disease" effects compared to other deleterious effects.

To summarize, it is believed that there are factors other than the aforementioned deleterious effects which are most directly involved in the actual design trade-offs facing planners of regional waste disposal systems. These factors are discussed in the following subsection of the report. Many of the deleterious effects, as outlined above, are of interest to the extent that acceptance levels are necessary as specifications for systems being designed and evaluated. Some of the effects are reflected in land use, conservation, and other economic factors, and therefore should affect the measures to be discussed.

2.4 An Approach to Measurement of the Effectiveness of a Regional Solid Waste Management System

The following is a discussion of effects which are not directly concerned with public health per se, but which are measures of effects which can be crucial to the success or failure of any solid waste management system. Specifically, these are:

(a) Production of Saleable By-Products

(b) Salvage of Resources for Return to the Economy

(c) Conservation of Land Resources

There is a widespread feeling around the country that one of the more serious bad effects of common solid waste disposal practices is the dissipation of the nation's resources.[4] It follows, therefore, that a good system is one which conserves these resources to a large extent. In its most extreme form, this argument stresses those cases where wealth is actually produced in the waste processing/disposal cycle. For example, the value of compost created within a system is an indicator of its effectiveness, and the enhanced value of swamp- or tide-land reclaimed as the result of fill operations is another indicator of effectiveness.

As far as wealth-enhancing effects are concerned, the provisions of the Solid Waste Disposal Act do not specify that production of wealth is a major objective of any waste-management system. To the extent that it would be established as an objective, one is dealing with overall regional or national economic planning--a much higher decision-level. For this situation, an appropriate system analysis would investigate the role of solid waste management as a subsystem within the regional economic system and a measure specific to the operations of the subsystem as a part of the economic system would have to be defined. It is not at all clear that the item of wealth-enhancement attributed to the solid waste management subsystem constitutes such a measure. In other words, the subsystem which produces the most wealth, for a given level of costs or investment is not necessarily part of the regional economic system configuration which produces the most wealth for a given expenditure.

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[4] In establishing the Solid Wastes Program of the National Center for Urban and Industrial Health, the Surgeon General of the Public Health Service noted the following provision of the Solid Waste Disposal Act..."to initiate and accelerate a national research and development program for new and improved methods of proper and economic solid waste disposal, including studies directed toward the conservation of natural resources by reducing the amount of waste and unsalvageable materials and by recovery and utilization of potential resources in solid wastes."

On the other hand, it does seem that the conservation of resources gets close to the heart of the solid waste management problem. When considering the land resource, the need to conserve resources is not only a long-range desideratum or a higher-level ideal reflected in indirect ways in decisions made with regard to solid waste management, but is related in a most direct way to the problem at the operating level. The scarcity of land near the population centers for which there are few or no competing land uses, and the knowledge that if land in the less densely populated areas is used for waste disposal, it might not be available to society at the time other competing land uses become manifest, are problems faced every day by regional officials in planning waste processing and disposal facilities. So it would appear that a subsystem which, for acceptable levels of air pollution and water pollution, and for a given level of expenditures, competes the least with other land uses (in other words which conserves the most land) as the region develops, is highly desirable. In this sense, some of the wealth-enhancing effects dismissed previously as being tangential, such as land reclamation, now actually do tend to indicate high system effectiveness for given cost levels. For while no credit has been given the system for the wealth (land) it has (for all practical purposes) created, credit is given the system by virtue of its not having used a corresponding acreage of scarce land resource somewhere else.

Much the same argument could be made with regard to resources other than land; in other words, the measure of effectiveness could reflect the quantities of raw materials returned in various forms to society rather than destroyed. Saleable by-products then are interesting not as examples of wealth-enhancement but as conserved resources. The desirability of including this measure depends on the basic objectives set for the waste-disposal system. Essentially, it relates to the time-frame of the problem: the more one wants to provide a tool useful over, say, fifteen, twenty or even thirty years, the more appropriate it is to adopt a measure of effectiveness which incorporates land conservation. The more one wants to look ahead, working from the attitude that it is economically undesirable to dispose of materials rather than recycling them through the economy, the more desirable, even necessary, it is to include the conservation of other resources than land. Of course, the scarcity of the materials to be conserved would have to be considered, and the economies associated with the conservation of the specific materials. It would appear that this type of consideration should most appropriately be introduced at several levels of decision-making higher than the regional waste management or solid waste management levels.

It is concluded as the result of the arguments included here and in Section 2.3 that to be most useful for decision-making with regard to the configuration of the regional solid waste management system, the measures of effectiveness should include the factors related to conservation of the land resource. The land use and land availability aspect should be emphasized since, unless solid waste is converted so that one essentially turns the problem into an air pollution or liquid waste problem, the waste must in one form or another be returned to the land. It should be recalled that the solid waste handling problem as such did not achieve nationwide seriousness until the scarcity of land in various localities became critical. It appears (although it involves a reverse of scale, resulting in a measure of ineffectiveness) that a natural measure is the number of acres of land devoted to waste disposal and for which there are alternative (competing) land uses.

In order to measure the effectiveness of a given solid waste management subsystem according to the approach just outlined, it would be necessary to first define the time period over which the system is to be utilized, and the types of facilities within the system. For any trial system, the sites of all facilities to be used during the period, and estimates of the amounts of time within the time period that each will be used for solid waste handling purposes should ideally be designated. This might prove to be a difficult item to provide where the utilization time period is long or where the system concept is still in preliminary form. It is not infrequent that regional officials have only a general idea of the locale of their next generation of landfills, say ten to fifteen years into the future. In these cases a cubic yardage requirement would have to be combined with knowledge of the terrain characteristics of the general neighborhoods of the predicted sites in order to derive an acreage estimate.

To be consistent in the application of the concept of minimizing interference between handling operations and expanding demands for land for other uses, the acreage counted should not only include the processing and disposal sites proper, but also adjacent or attached parcels of land whose use will be limited by virtue of the existence of the processing and disposal facilities. The inclusion of additional acreage or a buffer zone would accomplish several things. First of all, it would account for the relative undesirability of sites within the highly developed urban areas because of the presumed higher tendency to encroach upon neighboring properties in terms of restricting land use or preventing higher real estate values. Moreover, it would allow the desirability of good disposal practices to be manifest by reducing the adjacent acreage which is negatively affected. Thus, open dumps should be highly ineffective, unless they are isolated within a sparsely populated area, by virtue of relatively large areas affected by them compared to, say, well-operated sanitary landfills. On the other hand, such examples as the Palos Verdes Landfill in Los Angeles County, California would contribute low ineffectiveness (i.e. high effectiveness) because there are virtually no negative effects on the neighboring properties.

For those cases mentioned above where only approximate site locations are given it would be necessary to develop general rules relating the distance from the boundary of a disposal site adversely affected, to sites of various types and to sites within surrounding areas of various types. Ideally, it would also be necessary to compile information on the "recuperability" of land used for disposal purposes; that is on the lengths of time required for settling, etc. before the land can be used for various alternative purposes.

The information indicated in the preceding paragraphs, that is, acreage estimates of all facilities to be used during the period, the time segments of the period during which each will constitute a denial to the region of lands which would have been available for other existing purposes, amended to account for effects on adjacent land, would be combined to yield the "ineffectiveness measure". The total acreage required for solid waste handling purposes would be determined as a function of time. The function would be the basis of an effectiveness measure to be used within the systems analysis of the regional solid waste management system.

2.5 Other Measures of Effectiveness

Several other measures of solid waste system performance have been suggested, namely:

- Convenience to the Waste Producer
- Adaptability to Statutory or Other Changes in Requirements.
- System Reliability

Certainly all of these are desirable properties of solid waste management systems. Here again, there is a question of the degree to which these factors are "traded off" during system design, or whether some acceptable performance level is established.

Although the convenience pattern appeared too well-established in many municipalities within the SMSA to admit any trading-off (e.g. it would be politically impossible in the City of Buffalo to remove roll-out service) there are evidences in the newly developing areas of the Region (where the individual contract with a private collector is still the rule) that some cost-vs.-convenience weighing is explicitly practiced when more highly organized forms of collection and disposal are considered or established. And there have been ample evidences of a willingness on the part of Erie County officials to pay more for a system which would not put County disposal operations at the mercy of the officials of a single town who might have an unanticipated change of heart at a future time. Thus it appears that some trading-off is actually practiced with regard to the adaptability factor. Finally, municipal and County officials in the SMSA are well aware of the dangers of operating with a single facility without a viable alternative to use in emergencies, and of the fact that they are incurring expense in order to avoid unreliable service. Although they are not treating this factor quantitatively, they are implicitly weighing costs against reliability.

It appears that these factors hold some promise as measures of effectiveness. Especially with regard to reliability, these factors appear to lend themselves to quantification to an encouraging degree. Since other measures (i.e. costs, acreage, pollutants of the various types) appeared more promising, however, in providing a first cut at systems analysis in regional solid waste management, these measures were not subjected to substantial investigation in the face of more pressing study requirements.

SECTION 3. THE STRUCTURE OF REGIONAL SOLID WASTE MANAGEMENT SYSTEMS EVALUATION

3.1 Purpose of Studying the Structure

In this section the methodological structure of evaluating regional solid waste management systems is examined. The elements of the evaluation process are identified and the relationships among the elements are traced.

The structure given can be considered a generalized system analysis model in the sense that many models which may be proposed for the analysis or evaluation of waste management systems would fit within this general structure. Indeed, if submodels and data of sufficient quantity and detail were available, or if the time required to develop and/or gather these were available, an evaluation model identical to the structure presented here might be contemplated. For present purposes, however, the structure is not considered a model since it does not allow for the actual manipulation of information nor can it be used as such to produce results used in system analysis.

Construction of the model structure represents a necessary step in the process of developing an appropriate system analysis approach to the solid waste management context. A vehicle is provided wherein different system analysis models can be examined in an orderly way and compared with regard to scope, overlap or complementarity, and compatibility. In terms of the elements which comprise any system evaluation in the solid waste context, it is easy to clarify with respect to any specific system analysis model exactly those elements which are: (i) held fixed, (ii) those which are being varied parametrically, (iii) those which are being simulated or modelled, and (iv) those which must be supplied as input data. There follows from the step of developing the structure a number of decisions regarding "first cut" analyses that can be made and the modelling and data needs required for them. Also there follows a more definite specification of modelling and data gathering steps which should closely follow in order to yield operationally-useful systems analyses as early as possible. Section 3.6 contains a description of specific guidance to current and future work yielded by the evaluation structure.

3.2 Major Elements of the Structure

In Section 3.3, the systems evaluation structure is presented in detail. The following material provides an overview of the major features of the evaluation structure with regard to information types within any evaluation model. Fig. 3 contains this overview model structure.

The structure consists of the essential elements required for the assessment of candidate regional solid waste management systems. Some attention has been given to the collection function in this structure in recognition of the fact that this function is a factor in systems evaluation in general. It is noted that the decision in Erie County to leave collection to the individual municipalities is in effect an implicit judgment that minimal acceptable collection service can be provided in this manner at acceptable costs. Secondly, the collection function is shown in order to illustrate the role played by this factor in relationship to other factors. Before describing Fig. 3 in more detail, several fundamental comments should be made with regard to this structure.

First of all, the structure is based on the idea, already expressed in Section 2, that solid waste management is an interrelated portion of the total waste management system, and therefore the evaluation of the solid waste management system must yield measurements of air and water pollution along with its other outputs. Furthermore, land use measurements as they relate to urban, surburban, and rural portions of the region are important in evaluating the solid waste management system. By this is meant the acreage used in the various portions of the region by any candidate system being evaluated. Similarly, within the developed areas, it is of interest to measure the acreage used by the system in portions of those areas characterized by generalized land use; e.g. the residential, commercial, and industrial portions of the developed areas.

PAGE NOT

AVAILABLE

DIGITALLY

If one "exercises" the model structure a single time through, it will only yield measurements of the types indicated in Fig. 3 and will not, for example, yield deleterious effects data or other indirect cost data except to the extent that these are represented by air pollution, water pollution, and acreage use measurements. This does not mean that the latter are not represented in the analysis, however, for system analysis is viewed as involving many runs of the evaluation model, where the input data are varied parametrically to correspond to different candidate systems. Among other parametric variations that may be contemplated are some representing an assortment of performance or service levels. A series of runs in which, as an example, the operating standards at landfills are systematically tightened or improved so as to affect costs, capacities, and the types of waste which might be routed to the various disposal sites, would effectively yield information relating landfill indirect costs to the direct costs and to the other measures of effectiveness of the solid waste management system, even though Fig. 3 does not explicitly show means of deriving such relationships. Fig. 4 represents an evaluation model structured as in the remainder of this section (Section 3) being used within a series of runs over which performance standards are systematicaly varied, in order to generate information relating to indirect costs or deleterious effects.

Related to the previous comment, system optimization or other management decision-making guidance can be provided by the model structure only by means of series of runs with system characteristics systematically varied from run to run. Thus there is no place in the structure for decision-making with regard to (e.g.) source (refuse generation) area - facility assignment or time-phasing of processing plant capacities; only the results of any decision or possible decision can be given by the evaluation structure as given. From this point of view, the advantage of decision algorithms can be looked upon as requiring a reduced number of "runs" through the evaluation model in order to reach a system configuration which yields satisfactory cost and performance measurements.

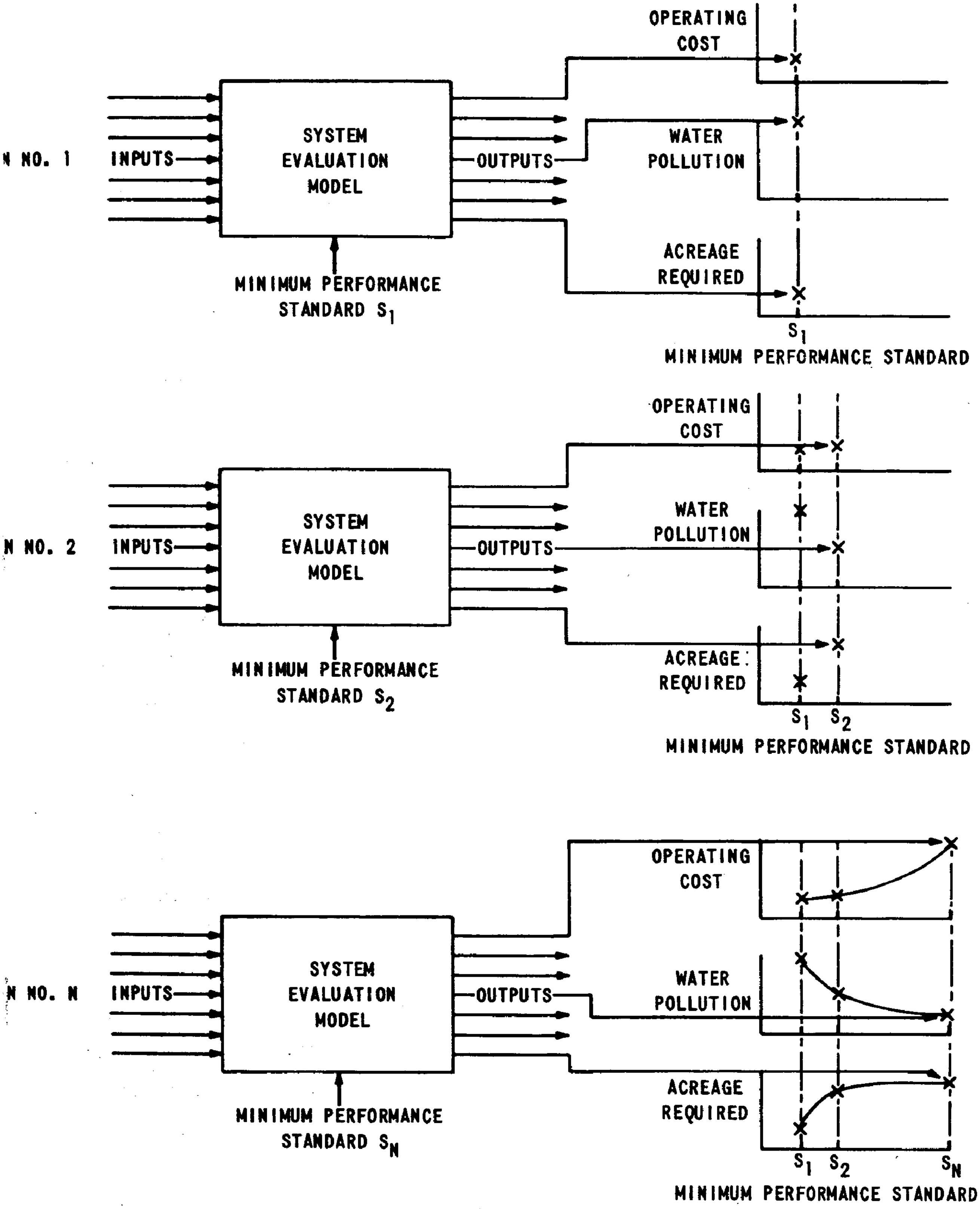

Figure 4 AN EVALUATION MODEL WITHIN A SERIES OF RUNS

Another way of viewing the relationship between decision-making algorithms or optimization models, as discussed in Section 4, and the evaluation structure of this section is more germane to the conduct of the present study. System analysis, being concerned with most efficient operations under stated conditions and with the balancing of conflicting factors, is necessarily involved with optimization analyses and decision algorithms. The development of the evaluation structure helps to reveal optimization models which might be designed, and helps the analyst to decide which of the many models possible might be the most fruitful.

Finally, it should be noted that the structure includes considerations of material flow, cost budgeting, and an evolving solid waste system. Candidate systems can be examined over t time periods without restricting the examination either to a single time period (e.g. one year) or to a prespecified time period (e.g. 20 years or to the year 2000).

Referring to Fig. 3 , the locations and quantities of refuse by type for Erie County and at a specified time period (e.g. 1966) are established The degree of refinement in classifying the solid waste types is in large measure dependent on the properties of the processing plants and disposal sites being examined. So as to allow for the broadest range of systems to be examined, the categorization of solid waste is sufficiently detailed so that differences in plant and site technology could be measured. Based on a set of routing algorithms or disciplines, the regional solid waste, by location and type are assigned to specific processing plants and/or to disposal sites. In either case, specific accounting, in the aggregate, is made of the quantities, by type, which are transported to the processing plant and/or disposal site. Maintaining information of this nature then allows for a period-by-period comparison of the material processing and disposal requirements and the extant available capacities of these facilities. Within the structure, additional facilities with their associated capacities are scheduled for and thus a time-phased routing schedule is established.

The outputs to be derived relative to candidate solid waste systems are:

- o Gaseous wastes and air pollutants, by type and quantity
- o Liquid wastes and liquid pollutants, by type and quantity
- o Processing by-products with respect to processing plants
- o Acreage occupied and "influenced" by plants and sites, by subregion type.

For each of the major activities, including the direct cost of collection, a cost budgeting is made. By direct cost of collection is meant those costs associated with the handling of the solid waste up to the time when the waste is in direct transit to the processing plant and/or disposal site. Included within the cost budget for plants and sites are the capital or investment costs, the operating and maintenance costs of the facilities, and finally the transportation costs for handling the solid waste from the source areas to the processing plants and then to the disposal sites or to the disposal sites directly.

This in summary is an overview of the evaluation model and some of the factors being introduced into or underlying the model structure. Upon completing the computations for a single time period, many of the inputs require updating (e.g. volume of solid waste generated based on per capita generation rates, changes in population, and economic activity; processing plant capacity increases (if required), disposal site residual capacity, etc.). With these new inputs, the computation for the next time period is initiated. Thus for any prescribed number of time periods, information is available, on a time series basis, of the effectiveness, costs, pollutants derived and, if and what types of performance standard violations have been experienced. This last output is established under the conditions that acceptable performance standards with respect to the deleterious effects have been specified for that "run" through the evaluation model.

3.3 The Finer Structure of Solid Waste Management System Evaluation

The flow diagram in Fig. 5 represents the finer structure of evaluation of a solid waste management system. Besides providing more detail than the structure as presented in Fig. 3 , this representation differs in its greater resemblance to an actual computation model. Where the overview structure emphasized data types and their relationships to one another, this structure concentrates on specific data items and the order in which they may be developed one from another, following a predesigned set of computational instructions.

In examining the flow diagram it may be helpful to consult Table 2, which contains a key to some of the symbols used.

For the reasons indicated in Section 2, the primary emphasis of the model is directed toward the solid waste processing and disposal functions. The collection function of the system is treated from the viewpoints of transporting the waste from individual source areas to processing plants or disposal sites and assigning a cost of the actual collection. Future generations of this structure or a large-scale working evaluation model would incorporate collection routines which allow for assessments of alternative collection systems, and the implications of regionalizing this function along with the other functions of the solid waste handling system.

The first significant steps in the structure are the computational routines for determining the quantity of solid waste to be collected prior to subsequent processing and disposal. The total quantity of solid waste to be collected differs from the amount generated by such activities as on-site processing and/or disposal sites includes grinders, incinerators, compost heaps, and some forms of on-site dumping or land filling. In those regions where on-site open burning is permissible,

PAGE NOT

AVAILABLE

DIGITALLY

Entity	Indexed by	No. of Given Entity Contained in System
TIME PERIODS	IT	NTPER
SOURCE AREAS	I	NSAREA
PROCESSING PLANT TYPES	J	NPLTYP
PLANTS OF TYPE J	IP	NJ
DISPOSAL FACILITY TYPES	K	NDFTYP
DISPOSAL FACILITIES OF TYPE K	ID	NK

this form of processing would be included. Since Erie County does not permit on-site open burning, this process would be excluded from the options available in applying the structure to local problems. In addition to computing the reduction in volume and weight, estimates would be made of the gaseous components and particulate matter introduced into the air, and the quantity of material to be processed at the sewage treatment plant.

The next two major blocks of steps in the structure involve analyses of the processing plants and disposal facilities. These steps are outlined together since the form and outputs of each analysis are quite similar. For each plant of a specified type (e.g. incinerator, compost, etc.), a material-time flow is maintained and based on its operating characteristics, estimates are derived of the gaseous effluents, particulate matter emitted, sewage outputted, by-products recovered, residue derived and the processing costs entailed. These estimates are then aggregated for all plants of a given type. A comparable set of calculations and estimates are made for all the processing plant types, over all source areas whose solid wastes are transported to these plants and over the time periods being investigated. The residue or reduced solid waste is then transported to the appropriate disposal facility which had been previously determined and stored within the routing data store. In examining the disposal facility routine, the primary differences from the previous stage are (a) the determination of the capacity utilized by the waste transported directly from source areas or residue from processing plants and (b) the estimates of the water pollutants. In both the processing plant and disposal site routines, computations are made of the acreage affected. As mentioned previously, the land affected is the land actually utilized plus the buffer zone. The size of the buffer zone is a function of the location of the facility (urban, suburban or rural, residential, commercial, industrial), and the types and levels of the deleterious effects.

As illustrated within Fig. 5 , the outputs derived are:

Disposal Costs
Processing Costs
Transportation Costs
Remaining Capacity at the Disposal Sites
Acreage Used or Affected, by Subregion Type
By-Products, by Type
Liquid Wastes and Water Pollutants
Particulate Matter Emitted
Gaseous Effluents, by Type

In addition to the outputs, estimates are made of the collection costs, and a determination is to be made regarding violations of preset minimal performance standards with regard to deleterious effects. The latter determination is discussed further in the succeeding Section 3.4.

3.4 A Minimum Acceptable Performance Screen

Before performing an evaluation of any candidate system or subsystem within the formal evaluation structure, an initial filtering or screening procedure of the processing plant or disposal facility with respect to its associated deleterious effects would be made. Information would be gathered from and with responsible regional officials to obtain regionally-acceptable deleterious effects constraint levels. Alternatively, trial levels can be set in order to assess the effects on the system of various acceptance levels. Thus the filtering process involves, for individual plants or facilities, a comparison of its deleterious effects (individually) and the appropriate constraint level. Where the plant or facility either operates below the constraint level (pass when below, reject when above) or can be modified so as to operate below, the candidate is admissible for system evaluation. For each subsystem which cannot meet the levels prescribed, that is, does not pass all levels, the sub-system is not considered for further evaluation. To the extent that this filtering can be accomplished, this step insures first that the candidate system to be evaluated performs within the regionally-derived deleterious effect constraint levels and secondly, eliminates the need to perform the lengthy evaluation (over time and source areas) of systems which would be rejected.

Further attention is given in Appendix E to the formal aspects of construction of minimal acceptable performance screens.

3.5 Requirements for Submodels and for Input Data

The requirements for submodels and input data are lumped together since they are to a large extent complementary: a required item must either be supplied directly as input data or else must be generated by means of a submodel. In the latter case, other, more basic, data items will be required as inputs. For example, refuse quantities for all future time periods can be required as inputs, or alternatively, these can be derived by means of planning-type population and land-use projections and a submodel relating refuse quantities to populations and to economic activity. In the latter case, the planning projections would be required as inputs, as would the parameters of the submodel.

Thus it is almost inevitable that there be some lack of definition in submodel and data requirements, since it is not appropriate during development of the evaluation structure to be rigid regarding the choice of elements to model and those data to supply directly. The list of requirements which follows is consistent with the structure as given in Fig. 5. It should be understood in the light of the preceding remarks that deviation from this list of "requirements" will occur in actual evaluation model design due to unavailability in the field of certain types of data, or due to the evident difficulty of deriving submodels of various types. It would be desirable in analyzing a given region to know the constituency of refuse material as well as the quantity in order to assess, for example, the effect of introduction of more household garbage grinders. This data is not likely to be available for many regions, so a submodel relating constituency to (say) family size and/or income might be preferred. To give another example, the operating characteristics of incinerators as functions of the input refuse material appears to be an extremely difficult modelling task. Therefore, for the present the analyst must be content with results based on operations on refuse with "average" constituency. Data on the latter are relatively easy to come by.

3.5.1 Submodel Requirements

In order to satisfy the structure given in Fig. 3, it would be useful to have the following submodels. However, as noted above, in those instances where the basic data required by the submodels are not available or the internal submodel relationships are unknown, planning factor-type information can be utilized in deriving the needed data inputs.

(a) TIME-PHASED SOLID WASTES CONTENT AND QUANTITY PREDICTIONS

This submodel would relate per capita growth in refuse quantities, and content of residential refuse, to population characteristics (such as income, household size, and rural vs. urban characteristics). The outputs of this model would then be superimposed upon the population growth and projections of other population characteristics in the various source areas (typical regional planning information) to supply source quantity and content information for the residential sector for any future time period. Similarly, another submodel would relate refuse quantity and content to characteristics of commercial and industrial activity (such as size of firms, soft vs. hard industry, food processing or not) and superimpose this information on projections of levels of activity of the various characteristic categories in the source areas to obtain same quantity and content information for the commercial and industrial sectors.

(b) PROCESSING PLANT OUTPUTS

One submodel is required for each processing plant type (processing plants also include railroad and truck transfer stations). The submodel for a given process accepts variable quantities of refuse over some range of constituent materials, and, considering the parametric information describing the process and related anti-pollution devices, yields a description of the results of the process in terms of the following quantities:

- gas effluents by type
- particulate matter emitted
- outputs to the sewage system
- solid residue by type
- by-products by type

(c) PROCESSING PLANT COSTS

A submodel is required for each processing plant type which yields processing costs as a function of the size (capacity) of plant, the quantities processed, and the specific parametric information descriptive of the process. The submodel would distinguish between fixed and variable costs, so that given a specific location for a processing plant of a given type, acquisition and capital cost data specific to the locality, a total cost of processing can be determined for that plant which includes the fixed cost of establishing a plant at the specific location.

(d) DISPOSAL FACILITY OPERATION

This submodel accepts variable quantities of input to the disposal facility (site) over some range of constituent materials, and, considering the capacity of the site and the parametric information describing the disposal site operation, yields a description of the results of the operation in terms of the following quantities:

- volume utilized in disposal of refuse
- capacity remaining
- acreage equivalent of volume utilized

(e) DISPOSAL FACILITY COSTS

A submodel is required which yields disposal costs as a function of the size of the disposal facility, the quantities disposed, and the specific parametric information descriptive of the disposal function. The submodel would distinguish between fixed and variable costs, so that given a specific location and acquisition and capital cost data specific to the locality, a total cost of disposal can be determined which includes the fixed cost of establishing a disposal facility at the specific location.

(f) TRANSPORTATION COSTS

This submodel accepts as inputs a given routing schedule among source areas, processing plants, and disposal sites, together with quantity information and transportation equipment information specific to each route employed, and yields transportation costs. Incorporated in this model are the map-related constraints implied by the necessity of following the road/street network of the region in determining trip distances.

(g) LAND USE SUBREGIONS

A scheme is required for deriving the required division of the region into subregions with regard to urban, suburban and rural characteristics; with regard to predominant land uses (i.e. residential, commercial, industrial), and with regard to lands being in-use or not being utilized or committed. In the latter case, the non-utilized land must be classified according to its developability or usefulness for agricultural purposes. Application of the scheme to the subject region (in the present case, Erie County) would be required after completion of the methodological study.

3.5.2 Requirements for Input Data

Data required as inputs to the structure, assuming that it possesses submodels as just described, consist of the following:

(a) SOURCE AREA DESCRIPTIVE DATA

A source area is a closed geographical area which contains a population and in many instances commercial and/or industrial solid waste producing activities. Wherever possible, primarily in the region's towns, the boundaries of the source areas correspond to the U.S. Census Tracts. Within some cities (e.g., Buffalo) it may be preferable to use collection districts as basic source areas since most solid waste data is gathered and stored by collection districts. Data required for each source area are:

population
(categorized according to the requirements of the content-residential quantity prediction submodel)
commercial and industrial activity
(described according to the requirements of the content-non-residential quantity prediction submodel)
area

(b) MAP DATA

The location of each source area and each processing plant or disposal facility must be given, according to some coordinate system. Ideally, distances traversed should be determined by travel on existing streets and highways. Thus, unless a submodel is supplied which allows the traffic network to be "followed" automatically, the distances from each source area to each facility destination, and the distances between the inter-facility connections used by the system, must be given as inputs.

(c) REGIONAL PLANNING DATA

Projections of changes in population over time with regard to its descriptive characteristics and with regard to distribution over the region will be required to appropriately relate predicted quantities to subregions within the region. Projections are required also of levels and types of commercial industrial activity as distributed over the region. Since a description of all processing plants and disposal facilities is contemplated which includes a categorization of the location of the plant or facility according to subregional type, the commercial-industrial subregional projections will be required in order to relate the categorization to regional development over time.

(d) DESCRIPTIVE DATA REGARDING PROCESSING PLANTS AND DISPOSAL FACILITIES

Data requirements are dictated by the output submodels of the processing plants and disposal facilities, the cost submodels, and the requirement for land employment output information. Specific requirements are: Location and a Classification of the Location by Subregion Type. It appears useful to categorize the land within a region as urban, rural and suburban (less densely populated than urban but more so than rural). Furthermore within the urban category, the location of the plant or site should be further identified as to its relationship to industrial, commercial or residential land use. A somewhat similar categorization of land use within the rural and suburban subregions would be required.

(1) Acreage of Site

Given the location by subregion type, the acreage of the site is determined based on the land actually dedicated to the plant or site plus the necessary buffer zone about the plant or site. The purpose of the buffer zone is to reduce the amount of nuisance to the population and other land uses which are located within the vicinity of the plant or site. In part, the size of the buffer zone is a function of the deleterious effects which are associated with the plant or site and the location, by type, within which the facility is to be established.

(2) Process and/or Disposal Operations Parameters

These are the data required as inputs to the processing plant/disposal facility output submodels. They include such items as handling rates, material salvage properties, residue and pollutant-producing properties, depth of fill, compaction ratios, etc.

(3) Capacity.

(e) DESCRIPTIVE DATA REGARDING TRANSPORTATION EQUIPMENT

As inputs to the transportation cost model, the equipment used over each route followed must be known, as well as the number of truckloads of refuse hauled, for transportation costs are most easily handled on a cost per mile basis for truckloads of a given description. For the various types of waste transported and for the equipment used to haul those materials, one needs information regarding

- o Tons of solid waste per truckload or, if more handy, for the type of waste under discussion
- o Volume of waste per truckload.

(f) COST INPUT DATA

Input data are required by the various processing plant, disposal facility, and transportation cost submodels. These items primarily refer to the direct costs associated with the major solid waste system functions, for example the cost per mile of truckloads of given descriptions. Important additional items, however, are the fixed costs to be associated with facilities of various descriptions, given specific locations for them. These latter items reflect, among other things, land values in the various localities within the region.

(g) ROUTING INFORMATION

Any system description contains as part of its most basic data that information which prescribes the destination of refuse of the various types originating in each of the source areas. Furthermore, the residue or process output at each of the processing plants must have a specified destination or destinations determined from among the disposal facilities.

Since the evaluation structure is oriented toward yielding measurements on a given regional system, the routing information must be listed among the inputs to such a structure. However, efficient routings and choice of facilities is a prime subject of system analysis as described in Section 3.2; that is, in order to design a good system one determines (an iterative process) an efficient routing by conceptually evaluating a large number of trial systems with routings varied from trial to trial. Actually, this is accomplished by means of a facility selection and source area assignment algorithm.(See Section 4.)

It should be noted that routings and the set of active facilities cannot be made once and for all, for processing plants become obsolete and landfill sites become filled. Thus routing information must be time-related; that is, a prescription for origins (source area), intermediate stops (processing plants), and destinations (disposal sites) must be given for each time period covered. The prescription must be such that no plant is used longer than the design life of plants of that type and the capacity limitations of a landfill is not violated.

3.6 The Structure as a Guide to Analysis on the Current Project

The major contribution of the structure is in providing a guide to actual model-building on the current project. To be sure, given a study effort of appropriate length and support, it would be possible to develop a model corresponding to the entire structure, and go even further by computerizing the "routings" selection function. As a result, a comprehensive facility choice and source area assignment model would be achieved which permits evaluations of the system configuration thereby derived. Long-term efforts of this sort are being attempted; see for example [Ref. 15]. For present purposes, a modelling effort of more limited scope is appropriate, one which compromised among the following:

a) the effort could be completed in a relatively short time period;

b) the data required was readily available, preferably pertaining to the Buffalo area;

c) the output of the model could be put to use in assisting decision-making with regard to regional solid waste systems.

As already implied in the previous figures and in the foregoing discussion, development of rules for choosing among alternative facilities and making assignments of source areas to the facilities chosen is the central task of system analysis in the solid waste management context. Therefore, it was decided to develop a model of this type with a manageable level of detail. Consideration for the time involved on the one hand and data limitations on the other eliminated much detail from consideration as part of the model, for example, relating per capita generation of residential refuse to income or other population characteristics, relating commercial and industrial refuse generation to indicators of economic activity within various categories of industrial and/or commercial establishments, attention to constituent materials within the totality of refuse, introduction of distances "along the road network" as opposed to straight line distances.

It was planned to begin by treating the facility choice problem as a static problem (i.e. source quantities are constant over time and there are no capacity limitations on disposal facilities considered). Linear approximations to all processing, disposal, and cost functions would be assumed. The model derived would be applied to Erie County data in order to illustrate general applicability and capability to assist with a broad range of planning questions. Next, the approach adopted would be extended to planning for facilities with limited life and with capacity limitations.

The static model was developed and is the subject of the initial portion of Section 4. Following this material, the plan for the dynamic model is included in Section 4.7.

SECTION 4. A FACILITY CHOICE MODEL AS AN AID IN REGIONAL SOLID WASTE MANAGEMENT DECISION MAKING

4.1 Introduction

In this section, a model is described which yields, for a given set of potential facilities of specified types and locations,

a) a selection of those facilities, and

b) an assignment of source areas to facilities,

such that the total cost of the facilities and operations with those facilities is minimized over all possible selections and assignments. Both fixed and variable costs are considered. "Facilities" in this context refers to both processing plants (e.g. incinerators, transfer stations) and disposal facilities (i.e. sanitary landfills). In the case of processing plants, the model has the capability of choosing a disposal facility as the destination of the output (e.g. incinerator residue, transferred and/or compacted refuse) on a minimum cost basis.

It should not be inferred that providing minimum cost configurations from among a fixed set of potential facilities (which are associated with a set of performance levels of many characteristics which cannot be expected to behave in some well-ordered way) is the most that can be expected of system analysis in solid wastes management. Indeed, one needs only to look to the venerable open-burning city dump solution to the municipal disposal problem for evidence that a minimum-cost solution is not necessarily a best or even a good solution. The spirit of the approach is rather that from among system configurations which are equivalent in a system performance sense, or which represent a set of system performances among which there is no particular preference, it is best to choose that configuration which costs the least. Therefore, it is useful in several ways which are enumerated further on, to be able to find a minimum cost configuration from a set of alternative system configurations.

It has been observed that, even with explicit performance measurement set aside for the moment, there have been few tools for regional officials to use merely to accomplish cost minimization over a wide number of choices. The typical procedure appears to be solicitation of a handful of alternative system configurations from an engineering or planning agency within the regional governmental structure or from a consultant especially hired for the purpose. The costs associated with each of the alternatives are computed, and at best one achieves a minimum cost over the few alternatives considered. The choice of those alternatives, while not arbitrary, are nevertheless not systematically generated and one is left in many cases with the uneasy feeling that there are better alternatives which might have been considered.

The model presented in this section represents a contribution in at least these two modest respects:

- By enabling a large number of alternatives to be compared, thereby reducing the chances of ignoring a good alternative.

- By allowing, through series of runs under systematically varied input parameters, the characteristics of economically most desirable systems to be defined. Or, at the very least to obtain some idea of system configurations which are clearly inferior to other possibilities, given various combinations of input parameters such as processing and disposal costs, distances to disposal facilities, and volume reduction achieved during processing.

The latter point represents the first step in the direction of generating some principles of good system design. Answers to questions of the following types can be answered:

> What combinations of processing costs, distances to disposal sites, volume reduction achieved in processing, transportation costs, disposal costs, and refuse quantity generated in the service area of the processing plant make processing more economical than direct disposal?
>
> Are there areas within the region where such combinations are achievable through transfer station operations? Through incineration? Through more efficient incineration (greater volume reduction, reduced disposal cost)? Through cleaner incineration (increased processing cost)?
>
> In servicing all areas where processing is not indicated, what combinations of distances, disposal costs, transportation costs, and refuse quantities generated over various portions of the region correspond to situations where a single disposal site is the economical choice? What combinations indicate two landfills? Other numbers of landfills?

In answering questions such as these, it will be noted that the service levels implied by the parametric entries and the resultant outputs are not treated explicitly. However, every input figure represents some service level, at least implicitly, for a portion of the system. Runs under different cost parameters or operating parameters represent runs with systems having different operating characteristics. If these different operating characteristics correspond to differences in system performance with respect to increase or reduction of undesirable effects of solid wastes, the different minimum costs achieved under the several sets of operating characteristics represent the cost differentials among the several levels of undesirable effects. For example, it is noted above that cleaner incineration, in terms of air pollutants, can be represented by runs in which the processing costs are higher. The higher processing costs in the latter runs imply, in general, different minimum cost system configurations. Where incineration might have been economical under the higher air pollution level, it may be economical if cleaner operations are contemplated to eliminate processing and dispose of the refuse by direct landfill. The cost differential, between incineration with the original air pollution level and employing direct landfill methods for the area which would have been served by the incinerator, can be thought of as the cost of making the reduction in air pollution.

Note that for this argument to be made it is necessary that, under the higher air pollution level, the use of the incinerator in its assigned area be indicated by minimum cost considerations. In other words, if incineration were not economic over that service area, then the system cost could be reduced by eliminating incineration in favor of direct landfill, even without making the comparison with the cost of the contemplated incineration improvement. Assuming that the level of operations at the landfill were satisfactory, it would make no sense to associate this system cost reduction with anything except adherence to the principle that among alternative systems which are equally satisfactory on a performance basis, it is sensible to choose that system which minimizes costs. (In the same spirit, in the example where incineration is used even though direct landfill would be the minimum cost method, the cost differential could be interpreted as the cost of eliminating certain undesirable effects of landfills, or as a cost the community is willing to pay in order to conserve remaining landfill capacity.) This example illustrates the crucial role played by minimum cost considerations even though the evaluation of a system is not solely based on costs.

The implication of the preceding discussion is that there is a third respect in which the model presented in the following subsections represents a contribution to better regional solid wastes management system analysis, namely:

- By yielding, for any set of input values and possible choices of facilities, a unique cost which can be used as a normative value. Thus any system configuration which violates the choices and assignments corresponding to the minimum cost represents an additional cost which is presumed to pay for the elimination of some undesirable aspect of the minimum cost configuration.

This latter use of the minimum cost facility selection and source assignment model is the most valuable from the point of view of systems modeling. For it offers to regional officials a formal means of associating total system costs to system changes which effect improvements in performance in specified ways. While the model as it stands lacks the degree of detail which it might be desirable to have, nevertheless this notion of how to balance performance against costs appears worthy of trial.

Explicitly, then, the notion is to develop models whereby regional and/or local officials can derive the system costs of achieving various performance levels, where the latter is represented in descriptive, multivariate terms just as it is in the real world. No attempt is made to balance, e.g., a quantity of air pollution against a quantity of landfill leachant to the water table. Rather, the system description includes the descriptions of the incinerators and landfills as distinct items. In the simple model, the air and water pollution resulting from the facilities must be inferred; in a more complex model, these would be given as outputs. In either case, differences among various system configurations with regard to bad effects can be matched against cost differentials. An improved performance system will presumably be adopted by regional authorities if the cost differential is small enough.

The model described in this section was designed as a first step in the application of this notion to the specific problem context. Further development along these lines would include explicit attention to the time factor and the necessity for capacity constraints in the model as the sequence of decisions over time is considered. With the completion of this step, it will then be appropriate to develop a model which will include some of the detail omitted from the first stage model.

In Section 4.2, several special case problems are discussed in order to introduce the general approach and the notation. In Section 4.3, the model itself is described, and the potential of using it to weigh costs against elimination of undesirable effects of solid waste is made more explicit in Section 4.4. In Section 4.5 the experience achieved thus far with the model is discussed; the requirement for several facility submodels is noted in Section 4.6. Finally, a preliminary approach to the problem of extending this model to cover time-phasing of facility establishment and retirement is given in Section 4.7.

4.2 Basics of Source Assignment and Facility Choice Problems

In the following subsections, facilities are to be selected and assigned to service portions of some circumscribed region, which will be idealized as a closed region R in the (x,y) plane. A collection of I refuse sources is given, the location of the $i^{\underline{th}}$ source being at (x_i, y_i) $[1 \leq i \leq I]$. The quantity of refuse per time period is known for each i; this is represented by the symbol q_i.

The point sources (x_i, y_i) are idealizations of small areas such as census tracts, collection districts, or other functionally defined collections of residences and/or businesses which are geographically homogeneous. This discretization of the waste-generating mechanism is necessary because data (whether refuse quantities, or populations from which refuse quantities are inferred) do not exist in density form and only are available for discrete geographical sectors within any region under study. Were the other data of the problem extremely precise, it would be possible to construct a model which is based on individual households as source units and thereby have density of population represented in another form. However, a real case for the necessity of such fine detail would have to be made before embarking on such a costly and time-consuming course. It is postulated that the discrete representation is sufficiently fine for the present purpose of displaying the utility of this general approach.

4.2.1 The Decision to Install a Processing Plant - One Alternative Landfill Site.

The installation of a processing plant (incinerator, transfer station) is being considered, with its location at $(x,y) = (0,0)$ if the decision to install the plant is made. An available disposal (landfill) site is located at $(x,y) = (d,0)$, where d is in miles, and it is assumed that the site has adequate capacity for purposes of this problem. The problem is to distinguish that region, if any, where it would be preferable to use the processing plant, and the complementary region where it would be preferable to transport the larger volume of unprocessed refuse directly to the disposal site. Under the processing alternative, all refuse from a particular source i is transported to the processing plant, where it is processed and reduced in volume according to the ratio

$$p = [\text{volume of output}] / [\text{volume of input}]$$

The reduced-volume product is transported to the disposal site for final disposal. Straight-line distances are used in computing transportation costs. It should be noted that the preferences indicated are limited to the two alternatives given, and do not necessarily imply that one or the other will actually be adopted at a particular point (x,y) in preference to some third alternative.

The following unit costs hold:

c_P = cost of processing (\$/truckload)

c_T = cost of transportation of refuse delivered to facilities in collection vehicles (\$/truckload-mi)

c'_T = cost of transportation of processing plant output to the disposal facility (\$/truckload-mi)

c_D = cost of disposal of refuse or of processing plant output, assumed to be the same (\$/truckload)

Therefore, one has the operating cost of the incinerator for each unit quantity processed equal to $b_1 = c_P + p(c'_T d + c_D)$, and the corresponding operating cost of the landfill is given by $b_2 = c_D$. It is further assumed that the capitalization and fixed costs associated with facilities of either type are linear with daily capacity: that is, the capital cost per day of the incinerator is $A_1 + a_1 q_1$, if it is built, and that of the landfill is $A_2 + a_2 q_2$, where q_j stands for the daily capacity of Facility j (j=1,2). Thus the total cost is divided into fixed and variable portions, with the variable cost of processing and disposal of a truckload of waste generated at i, if processed at the incinerator, equal to $c_1 = a_1 + b_1$, and the variable cost of disposal of a truckload of waste generated at i, if disposed of at the landfill without processing, equal to $c_2 = a_2 + b_2$.

If d_{ij} = distance from Source i to Facility j (i=1,....,I; j = 1,2), then the total variable cost of processing and disposing of refuse collected at Source i (including transportation of the collected refuse to the incinerator or the landfill, but not including collection itself) is given by $(c_j + c_T d_{ij})q_i$ if Facility j is built and assigned to Source i. Using the constants defined, it is noted that for a specific source i it is cheaper to process or not to process according as $c_1 + c_T d_{i1}$ or $c_2 + c_T d_{i2}$ is the lesser. Supposing that $c_1 + c_T d_{i1} < c_2 + c_T d_{i2}$, but that refuse from Source i were transported to (d,0) for direct disposal rather than to (0,0) for processing before disposal, the overall system cost would be increased by $[c_2 + c_T d_{i2} - c_1 - c_T d_{i1}]\, q_i > 0$. Similarly, if $c_1 + c_T d_{i1} > c_2 + c_T d_{i2}$ but refuse from Source i is processed at (0,0) before disposal, the overall system cost would be increased by $[c_1 + c_T d_{i1} - c_2 - c_T d_{i2}]q_i > 0$. It follows that the sources where processing is preferable on a marginal cost basis and those where direct disposal is preferable on a marginal cost basis are separated by the boundary which is defined by the equation $c_1 + c_T d_{i1} = c_2 + c_T d_{i2}$, or

$$d_{i1} - d_{i2} = (c_2 - c_1)/c_T$$

In other words, the desired boundary is the locus of points where $\sqrt{x^2 + y^2} - \sqrt{(x-d)^2 + y^2} = (c_2 - c_1)/c_T$. Thus for $-c_T d < c_1 - c_2 < c_T d$, the boundary is given by the hyperbola

$$\frac{(2x - d)^2}{[(c_1 - c_2)/c_T]^2} - \frac{4y^2}{d^2 - [(c_1 - c_2)/c_T]^2} = 1$$

Where $c_1 > c_2$, the left-hand "branch" of the hyperbola will define the boundary, so that the regions will be shaped as indicated in Fig. 6(a). Where $c_2 > c_1$, the right-hand "branch" will apply and the regions will appear as in Fig. 6(b). If $c_1 = c_2$, the regions will be separated by the straight line $x=d/2$.

It is of interest to examine the various ranges of values of c_1-c_2 with regard to their operational meaning. The inequality $c_1 - c_2 \leqq -c_T d$, a condition where no hyperbola is defined, may be rewritten as

$$c_T d + c_P + p\, c'_T d + pc_D \leqq c_D,$$

which means that it is cheaper to process a cubic yard of refuse <u>generated at the disposal site</u> and then return the reduced-volume product for final disposal, than it is to dispose of it unprocessed without transportation. Under those circumstances it is clear that for <u>all</u> sources i processing is preferable to disposal at the given site. Just the opposite occurs when $c_1 - c_2 \geqq c_T d$, which may be rewritten as

$$c_P + pc'_T d + pc_D \geqq c_T d.$$

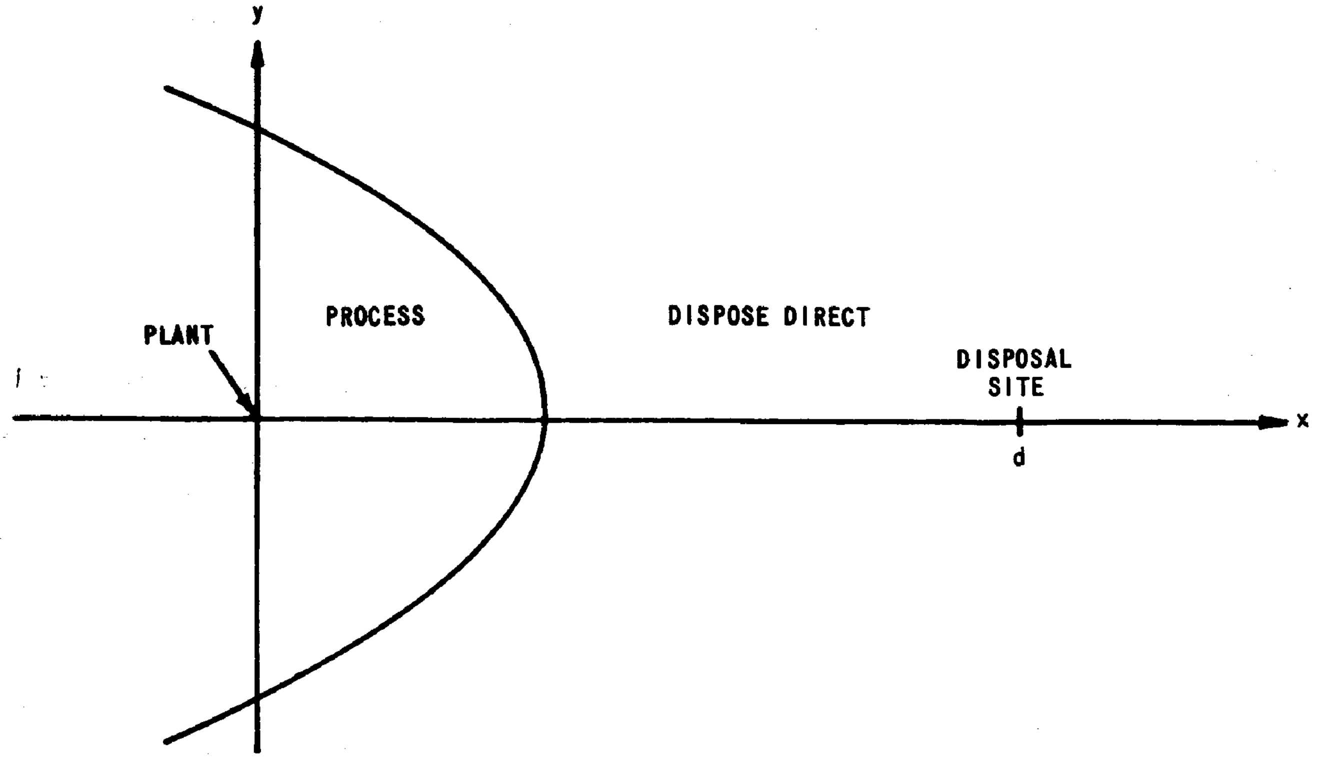

Figure 6 (a) BOUNDARY OF REGION WHERE PROCESSING IS PREFERRED, $0 < c_1 - c_2 < c_T d$

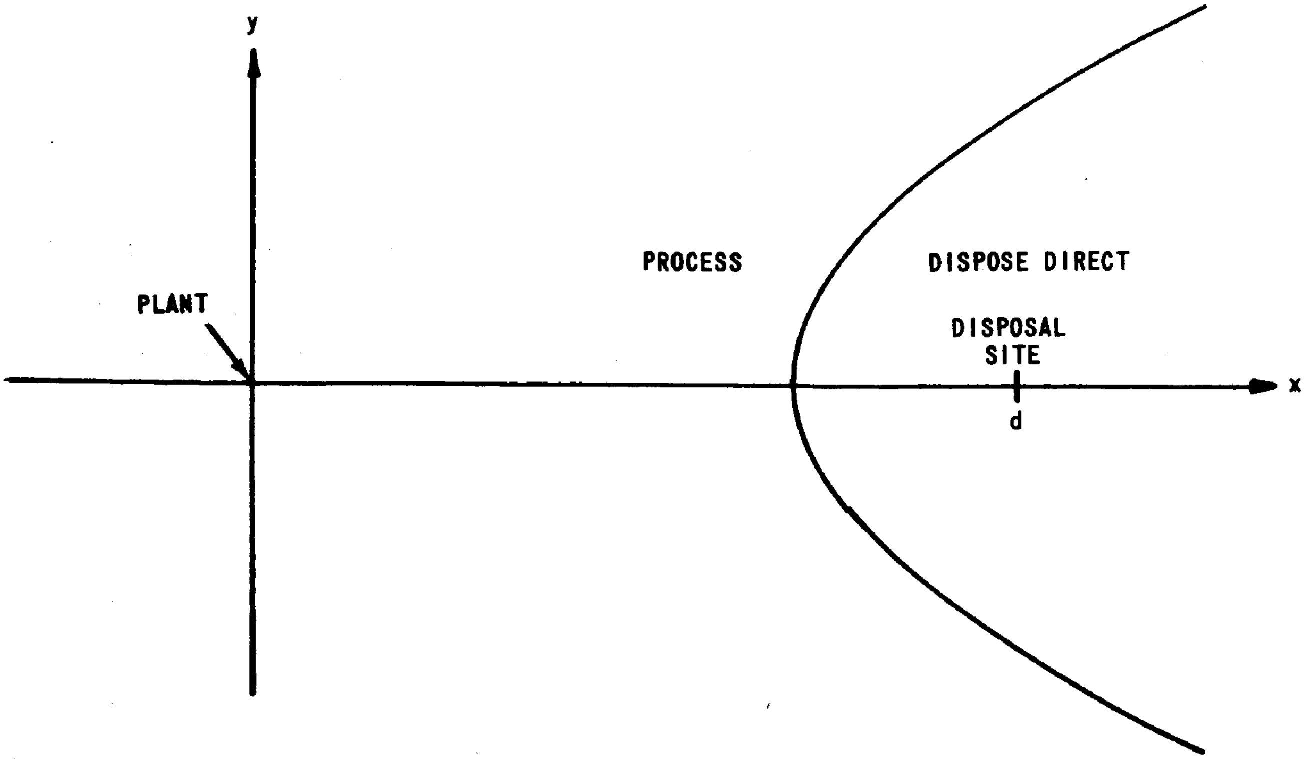

Figure 6 (b) BOUNDARY OF REGION WHERE PROCESSING IS PREFERRED, $-c_T d < c_1 - c_2 < 0$

The latter inequality means that a cubic yard of refuse generated at the site of the processing plant can be more cheaply disposed of unprocessed than processed. Thus for refuse generated at other sources i, it is *a fortiori* true that disposal at (d,0) without processing is preferable to processing.

The conditions $-c_T d < c_1 - c_2 \leqq 0$ and $0 \leqq c_1 - c_2 < c_T d$, which reflect the qualitative difference illustrated in Figures 6(a) and (b) in the shape of the region where processing is preferred, may similarly be given operational interpretation. The quantity $c_1 - c_2 \lesseqgtr 0$ according as

$$c_P + pc_T d + pc_D \lesseqgtr c_D.$$

The left hand side of this expression is the cost of processing and disposing of a cubic yard of refuse generated at the site of the potential processing plant. The right hand side is the cost of disposing of a cubic yard of refuse generated at the disposal site. In other words, the two alternatives are examined with regard to their basics as processes, independent of the locations of the facilities except that transportation of the product of the processing plant is accounted for under the processing alternative.

For illustrative purposes, let a_1 = \$4.50 per day. (A fixed cost expenditure each day of \$4.50 for each truckload processed on the average. At 3 tons per load, this is equivalent to \$1.50 per ton processed; for a 600T/da. incinerator with a life of 30 years (260 days/yr) this is equivalent to (\$1.5) x 600 x 7800 or \$7.02 million. Note that 600 T/da in this context refers to tons actually processed, not the daily capacity rating which is based on 24 hour operations; if only two-shift operations are used, the rating of this incinerator would have to be 900 T/da.) Let a_2 = 0, meaning the landfill is an existing, large facility. Let the other constants take the following values:

c_p = \$12 per truckload

c_D = \$ 3 per truckload

c_T = \$ 2 per round-trip mile per truckload

c'_T= \$ 2 per round-trip mile per truckload

$p = 0.2$

Then one has $c_1 = 4.50 + 12.00 + 0.2(2d + 3.00)$

$$= 17.10 + 0.40d$$

$$c_2 = 3.00$$

$$(c_1 - c_2)/c_T = 7.05 + 0.20d$$

According to the preceding analysis, since $c_1 > c_2$, a region resembling Fig. 6 (a) will exist providing $7.05 + 0.20d < d$, or $d > 8.8$. In other words, if there is available landfill space within 8.8 miles, one can't even define a region where incineration is potentially advantageous.

Interesting questions are raised by this conclusion for in fact there <u>are</u> existing incinerator facilities operating with available landfill close by. It is possible that the figures used are inaccurate, but the conclusion is so definitely dominated by the high c_p value that it is doubtful whether the relatively small changes which might result from more detailed study of the costs would cause a major qualitative change in the conclusion. At best, the value 8.8 might be raised or lowered. It should be kept in mind that in Erie County there are at least two examples of incinerators (Buffalo West Side and Cheektowaga) with disposal sites within a mile or two of them.

A better possible explanation is that the time factor plays no role in the analysis and that volume and capacity descriptions with regard to the given landfill area are not considered. It may be that the difficulties in acquisition of suitable areas and the limitations on the total available area suitable for disposal sites impels decision-makers to behave as if disposal were more expensive. In other words, higher values are imputed to c_D in order to allocate to each cubic yard of disposed material the acquisition costs and indirect costs involved in devoting land, a scarce commodity, to this particular use. For example, suppose c_D = 17.10 \$/truckload, with all other constants as originally given. Then $0<c_1-c_2=0.4d<2d$ for all distances d, and regions as illustrated in Fig. 6(a) result even for very small values of d.

To compare with incineration, consider a transfer station where the processing consists of compaction of the refuse into large-volume vehicles. Compaction in the transfer vehicle is assumed to be about the same as in the collection vehicles; i.e. p = 1.0. If the collection vehicles are one-fifth the size of the transfer vehicles (e.g. 15 cu. yd. vs. 75 cu. yd.) then if transportation costs are otherwise the same on a truckload basis, c_T remains as before but c'_T must be changed to \$2.00/5 or \$0.40. (That is, the 75 cu. yd. truckload costs one dollar per mile (one way), but each original 15 cu.yd. truckload is costing \$.20 after transfer). Disposal costs are the same as for the case of incineration. However, the unit processing cost is considerably lower: take c_P = 6.00 \$/truckload as a typical value. Also the fixed cost of a transfer station is lower: assume a_1 = \$1.35 (this corresponds to a 200 T./da facility with an initial investment of \$334,000 for building and hardware; of this, hardware which must be replaced every 10 years costs \$184,000. Thus over 30 years (7800 days) capital cost is \$150,000 + 3(184,000) = \$702,000, or \$90 per day. One has $a_1 = 90\ \$/\text{da} \times \frac{1}{200\text{T/da}} \times 3\text{T/truckload} = 1.35\ \$/\text{truckload}$.)

Then one has $c_1 = 1.35 + 6.00 + (0.40d + 3.00)$

$$= 10.35 + 0.40d$$

$$c_2 = 3.00$$

$$(c_1-c_2)/c_T = 3.675 + 0.2d$$

which is less than d whenever $d > 4.6$ miles. Thus the region where truck transfer is preferred to direct disposal without truck transfer cannot be defined if the disposal site is within 4.6 miles; whenever a site does exist which is further away than 4.6 miles, the region where truck transfer is preferred over direct landfill resembles the one pictured in Fig. 6 (a).

In the paragraphs above, regions of preference for service by a processing plant rather than by a direct landfill facility were described. Existence of an area where processing is preferred refers to a collection of sources such that, given that both facilities were in existence, it would be cheapter to be serviced by the processing plant rather than by the landfill with no intervening process. This still does not settle the question of when and when not to build the anticipated processing plant. If R consists of two non-overlapping areas R_1 and R_2 where processing is and is not preferred, and if R_1 is non-empty (the cases in the example above where d was sufficiently small to prevent the boundary hyperbola from being defined are cases where R_1 is empty and $R=R_2$), then further rules are needed to guide the decision on the building of the facility.

Recall that the capital costs associated with any facility consist of fixed and variable portions. Intuitively, it is clear that if the sub-region where processing is preferred is not a high-quantity generator of refuse, then the decision not to establish the plant should be made. Similarly, if the fixed costs involved in establishing the plant are sufficiently high compared with the landfill facility, the decision not to establish the plant would be made, since the high fixed cost would be large compared to the increased operating costs due to disposing without processing of refuse from R_1. This suggests that in order to appropriately make the decision regarding the establishment of a processing plant, the refuse quantities q_i [previously defined] and the fixed costs A_1 must be brought into the analysis.

Consider a disposal system in which all refuse originating in R_1 is processed before disposal while all refuse originating in R_2 is delivered to the disposal site (d,0) for disposal without processing. Let the symbol $\sum_S$, where S is a subset of the region R, be interpreted to mean "sum over all indices i for which (x_i,y_i) is in set S". If R_1 is empty, no processing is performed at all in R and the cost C of the system is the constant value L, where

$$L = A_2 + \sum_R (c_T d_{i2} + c_2) q_i$$

If R_1 is non-empty, the cost of this system is

$$\begin{aligned} C &= A_1 + A_2 + \sum_{R_1} (c_T d_{i1} + c_1) q_i + \sum_{R_2} (c_T d_{i2} + c_2) q_i \\ &= A_1 + L + \sum_{R_1} [c_T (d_{i1} - d_{i2}) + (c_1 - c_2)] q_i . \end{aligned}$$

Note that if it is assumed that the fixed cost A_1 of the processing plant is incurred, this latter expression is minimized over all partitions of R into two sets. For the square-bracketed quantity in the integrand is known from the previous section to be negative over the interior of R_1 and positive over the interior of R_2. Inclusion of an area outside R_1 in the area serviced by the processing plant would therefore increase C by the sum over that area of a positive quantity. Similarly, exclusion of an area within R_1 from the area serviced by the processing plant would increase C by eliminating from the latter the integral over that area of a negative quantity. In other words, if R_1 is non-empty, and if the fixed cost A_1 is incurred, no cost improvement is possible through rearrangement of the service areas. The only possible improvement is by saving the fixed cost A_1 even though R_1 is not empty.

That is, if C(system with no processing) < C(system where R_1 is processed) then the minimum cost system involves doing no processing in R_1 and the plant should not be built. This is because the savings possible through processing in R, are outweighed by the high fixed cost A_1 of installing the plant. The opposite condition, namely

$$L \geq A_1 + L + \sum_{R_1} [c_T(d_{i1} - d_{i2}) + (c_1 - c_2)]q_i$$

or

$$\sum_{R_1} [c_T(d_{i2} - d_{i1}) - (c_1 - c_2)]q_i \geq A_1$$

is the condition for deciding to install the plant and to use it to service the area R_1. The square-bracketed quantity is known to be non-negative over R_1, so it is clear that the inequality will be satisfied only if the quantity of refuse generated within R_1, i.e.

$$Q_1 = \sum_{R_1} q_i$$

is sufficiently large. This indicates why incineration, say, is relatively attractive for areas with high population densities.

Let us return to the examples previously given to see how these criteria apply in practice. Reflecting the preceding notion, we check whether an incinerator located within the area of highest waste generation (i.e. located in the central business district) is more or less favorable than locations of lesser waste generation density (i.e. quantity per day per square mile). Using 1966 municipal collection data from the City of Buffalo, and incinerator and landfill descriptive data as given above, the left-hand side of the inequality above was computed for various potential incinerator locations and distances to landfill. The results are given in Figure 7(a) through 7(c), where the variable cost advantage of incineration is plotted

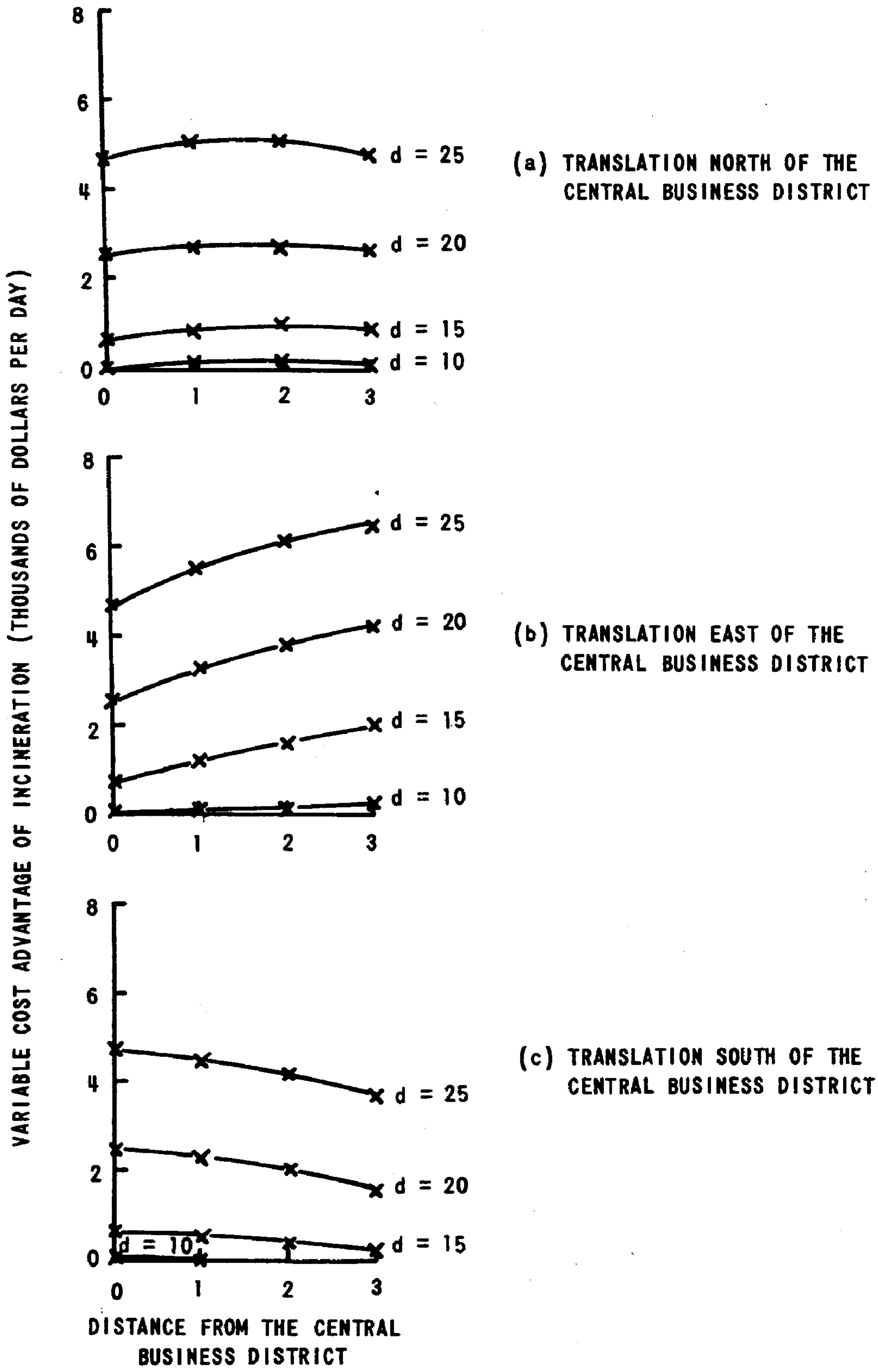

Figure 7 VARIABLE COST ADVANTAGE OF INCINERATION AS A FUNCTION OF DISTANCE FROM THE CENTRAL BUSINESS DISTRICT

against distance from the central business district. In (a), the locations are successively farther to the north, in (b) they are successively farther to the east, and in (c) they are successively farther to the south. One plot for each of the distances d = 10, 15, 20, 25 is given in each of (a), (b), (c); in each case the potential landfill location is d miles due east of the incinerator site.

The plots of Fig. 7 illustrate the following points:

(a) On the basis of transportation, processing, and disposal costs alone (i.e., excepting collection costs, where transportation of collected refuse is separated from the "collection" function) the distance to the landfill has a stronger effect on costs than the location of the incinerator within the city;

(b) The characterization of advantageous locations for processing plants is strongly dependent on the landfill locations.

In particular, the plots show that whatever the distance d, costs are relatively insensitive to relocations of the incinerator north and south of the central business district, but that the advantage that incineration has over direct landfill increases with easterly locations of the incinerator (i.e., in the direction of the landfill). In other words, if the potential landfill sites are all in one direction, it appears that the best location for one incinerator would be at the edge of town lying in that direction, providing that the variable cost advantage is large enough to override the fixed costs associated with the incinerator.

To illustrate the effect of fixed costs, Fig. 8 shows one of the curves of the previous figure, namely where d=15 and the potential locations are all easterly of the central business district. It should be noted that the vertical axis of Fig. 7 gives not only the variable cost advantage of incineration, but is also interpretable as the maximum fixed cost which would allow establishment of the incinerator. (This interpretation follows from the inequality which gives the condition for establishment of the

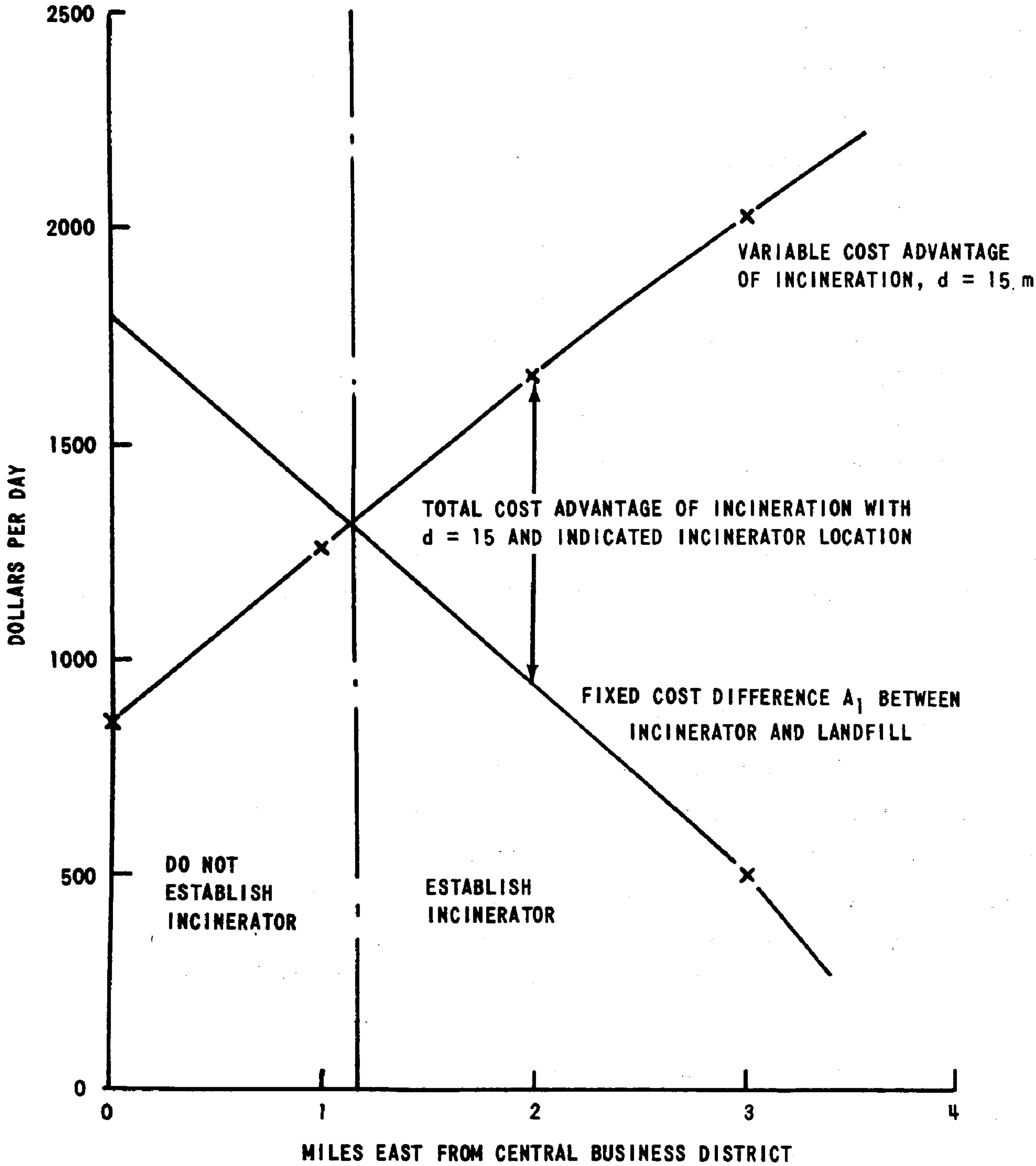

Figure 8 THE DECISION TO BUILD OR NOT TO BUILD AN INCINERATOR, ILLUSTRATIVE CASE

facility.) The second curve of Fig. 8 is an illustrative plot of A_1, fixed costs (on a per day basis) of establishing a basic incinerator, against distance from the central business district. It says that, primarily as the result of higher real estate values in the central business district, A_1= [fixed costs of a basic incinerator], expressed on a per day basis, is $1800 per day in the central business district and diminishes according to the illustrative curve down to $500 per day 3 miles to the east. The result is that no incinerator can economically be built (USING THIS ILLUSTRATIVE DATA) within 1.2 miles of the central business district. Beyond that distance, there is an advantage to incineration, which, in this illustration, increases with distance of the incinerator location east of the central business district. Locating the incinerator three miles to the east, it would be over $1500 per day cheaper to establish an incinerator than not to establish it (and use the landfill site 15 miles away.)

The drive of the analysis to place the incinerator at the edge of town is strongly influenced by the location of the unique landfill site. There will be more of a tendency to a central location under a (perhaps more realistic) assumption of several landfills, in some variety of directions. This could be examined with a model such as that of Section 4.2.3, where the decision to install an incinerator, against several alternative landfill sites is discussed. In the following Section, however, it is handy to first discuss the choice among a set of potential landfill sites and service areas assignments appropriate to the choice.

4.2.2 The Choice Among Several Disposal Sites in a Region

In Section 4.2.3, the decision to install a processing plant is examined for a region in which there are several disposal sites. In that section, the rule for deciding whether or not processing is preferred for a given source (x_i, y_i) is based on a comparison of the processing alternative with the best alternative for that (x_i, y_i) among all the disposal sites. Therefore, it is appropriate to examine the question of preferences among disposal sites prior to discussing the decision regarding whether or not to process.

Similar to the earlier analyses, no restrictions are placed on the availability or the capacities of these sites, except insofar as these may be reflected in the unit disposal costs. At this time, the number and location of sites are given, and there is no concern for the problem of appropriately locating sites and furnishing the most efficient numbers. It has already been pointed out how central to the entire approach it is for service areas associated with all facilities, including disposal sites, to be determined according to a minimum-cost criterion consistent with the one used in Section 4.2.1. It is, of course, of interest per se what the service areas, so determined, look like.

4.2.2.1 Simple Preference Among a Given Set of Disposal Sites

To begin, J disposal sites are given, the J^{th} site being located at the point (x'_j, y'_j) of R, $j = 1,\ldots,J$. Similar to Section 4.2.1, the capital cost per day of disposal site j is given by $A_j + a_j Q_j$ where Q_j is the daily number of truckloads delivered to the site, the operating cost per truckload is $b_j = c_{Dj}$ where c_{Dj} has the same interpretation as a unit disposal cost with respect to the j^{th} site as c_D did in Section 4.2.1 with respect to the disposal site of that analysis. Thus the total cost per day of operating the j^{th} site at a level of Q_j truckloads per day is $A_j + (a_j + b_j)\, Q_j$ where A_j represents a fixed cost and the sum $c_j = a_j + b_j$ represents a variable cost per unit.

Since it is assumed that the J sites are prescribed beforehand, the total $\sum_{j=1}^{J} A_j$ of the fixed costs represents an immutable portion of the total cost. Total cost minimization can be achieved only by making the total of the variable costs and transportation costs as small as possible. For present purposes, therefore, the fixed costs A_j can be ignored.

As in Section 4.2.1, let d_{ij} be the distance from Source i to Site j, i = 1, ... , I; j=1,..., J. Consider an arbitrary source (x_i, y_i) in R. The variable cost per unit, of transportation to, and disposal at, Site j is given by $c_T d_{ij} + c_j$. For a given i, it is preferable to dispose of refuse at that site which minimizes $c_T d_{ij} + c_j$ over all j, $1 \leq j \leq J$.

It is assumed that there are no two disposal sites j_1 and j_2 such that $c_{j_1} > c_{j_2}$ and

$$\sqrt{(x_{j_1} - x_{j_2})^2 + (y_{j_1} - y_{j_2})^2} < (c_{j_1} - c_{j_2})/c_T$$

Roughly speaking, this says that the difference in disposal costs between the sites is large relative to the cost of traveling between them. Suppose there were two sites satisfying the preceding inequality. Then if for some source (x_i, y_i), the inequality

$$c_T\sqrt{(x_i - x_{j_1})^2 + (y_i - y_{j_1})^2} + c_{j_1} < c_T\sqrt{(x_i - x_{j_2})^2 + (y_i - y_{j_2})^2} + c_{j_2}$$

were to hold, it would also be true that

$$\sqrt{(x_i - x_{j_2})^2 + (y_i - y_{j_2})^2} - \sqrt{(x_i - x_{j_1})^2 + (y_i - y_{j_1})^2} > (c_{j_1} - c_{j_2})/c_T$$

But there are no points (x_i, y_i) such that this occurs, for

$$\left| \sqrt{(x_i - x_{j_2})^2 + (y_i - y_{j_2})^2} - \sqrt{(x_i - x_{j_1})^2 + (y_i - y_{j_1})^2} \right| \leq \sqrt{(x_{j_1} - x_{j_2})^2 + (y_{j_1} - y_{j_2})^2}$$

for all (x_i, y_i) . (The latter is the triangle inequality.) It follows therefore, that for all (x_i, y_i), it is cheaper to dispose at Site j_2 than at Site j_i, and the latter can be eliminated from the problem.

Assuming that J sites are given, and that for each pair of sites j_1 and j_2 with $c_{j_1} > c_{j_2}$, the inequality

$$\sqrt{(x_{j_1} - x_{j_2})^2 + (y_{j_1} - y_{j_2})^2} \geq (c_{j1} - c_{j2}) / c_T$$

holds, then R is divided into J subregion $R_1, R_2, \ldots, R_J$, where by definition R_j is the set of all (x_i, y_i) in R such that

$$c_T \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} + c_j$$

$$= \min_{1 \leq j' \leq J} \left[c_T \sqrt{(x_i - x_{j'})^2 + (y_i - y_{j'})^2} + c_{j'} \right]$$

That is, R_j is the set of points (x_i, y_i) where disposal at Site j is preferred to all other sites.

Any pair of sites j_1 and j_2 implies a partition of R into two subregions, one where Site j_1 is preferred over Site j_2, and the other where Site j_2 is preferred over site j_1. Assume that $c_{j_1} \geq c_{j_2}$; then the boundary between the two subregions satisfies

$$\sqrt{(x - x_{j_2})^2 + (y - y_{j_2})^2} - \sqrt{(x - x_{j_1})^2 + (y - y_{j_1})^2} = (c_{j_1} - c_{j_2}) / c_T$$

If $c_{j_1} = c_{j_2}$, this boundary is a straight line*. If $c_{j_1} > c_{j_2}$, the boundary is half a hyperbola, specifically that half which corresponds to having a positive quantity on the right hand side of the equation. The effect is that Site j_1 is preferred within the convex region surrounding (x_{j_1}, y_{j_2}), and Site j_2 is preferred within the larger, complementary region, which includes (x_{j_2}, y_{j_2}). (It should be noted that Site j_1 has the more expensive variable costs.) Figure 9 illustrates the shapes of the regions of preference between two disposal sites.

Since any pair of sites gives rise to a partitioning of R by means of a hyperbola as just described (the straight line of the $c_{j_1} = c_{j_2}$ case is considered a degenerate hyperbola), and since finding the sub-regions R_j involves comparing the costs c_j for all pairs of sites, the process of defining the R_j is equivalent to checking the inequalities which hold in the subregions which result from superimposing the J(J-1) / 2 hyperbolas corresponding to the possible pairs of disposal sites. For example, R_j must be the interaction of the (J-1) sets

$$[(x_i, y_i) \text{ in } R \mid \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} - \sqrt{(x_i - x_h)^2 + (y_i - y_h)^2} \leq (c_h - c_j)/c_T]$$

defined for $1 \leq h \leq J, h \neq j$. The latter are distinguished by means of (J-1) of the total of J(J-1)/2 hyperbolas of the problem, specifically the (J-1) hyperbolas corresponding to comparisons with Site j.

To illustrate, ten landfill sites were selected arbitrarily as potential landfill sites for non-urban Erie County. These locations are indicated by the circled numbers of Figure 10 . In this illustration, the costs associated with all facilities are assumed to be the same, $c_j = 3.00$ as in the previous section. Transportation costs are also carried over from there, $c_T = \$2$ per truckload.

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*Specifically, the perpendicular bisector of the line segment connecting (x_{j_1}, y_{j_1}) with (x_{j_2}, y_{j_2}).

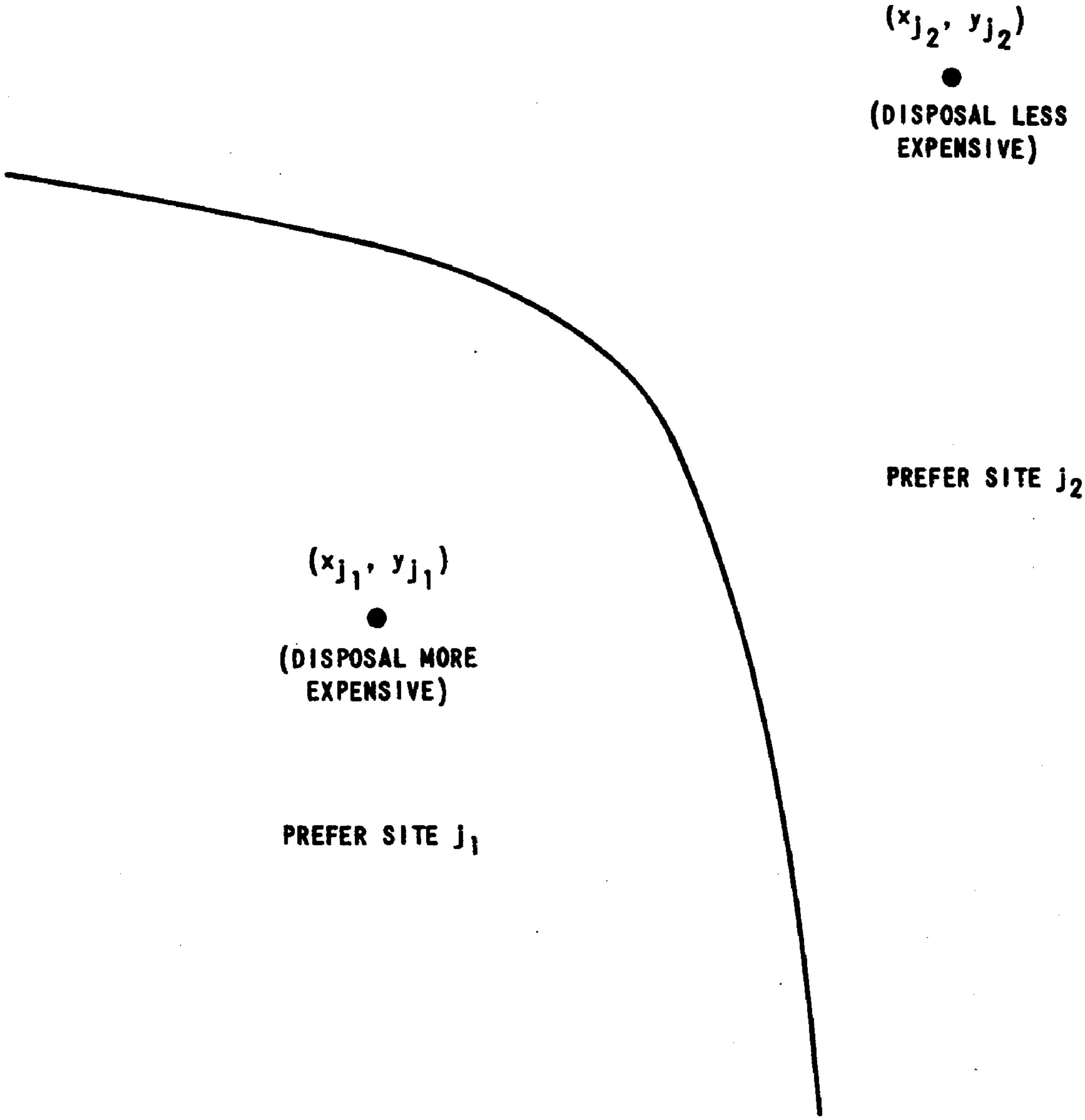

Figure 9 REGION OF PREFERENCE BETWEEN TWO ALTERNATIVE DISPOSAL SITES, $0 < c_{j_1} - c_{j_2} \leq c_T\sqrt{(x_{j_1} - x_{j_2})^2 + (y_{j_1} - y_{j_2})^2}$

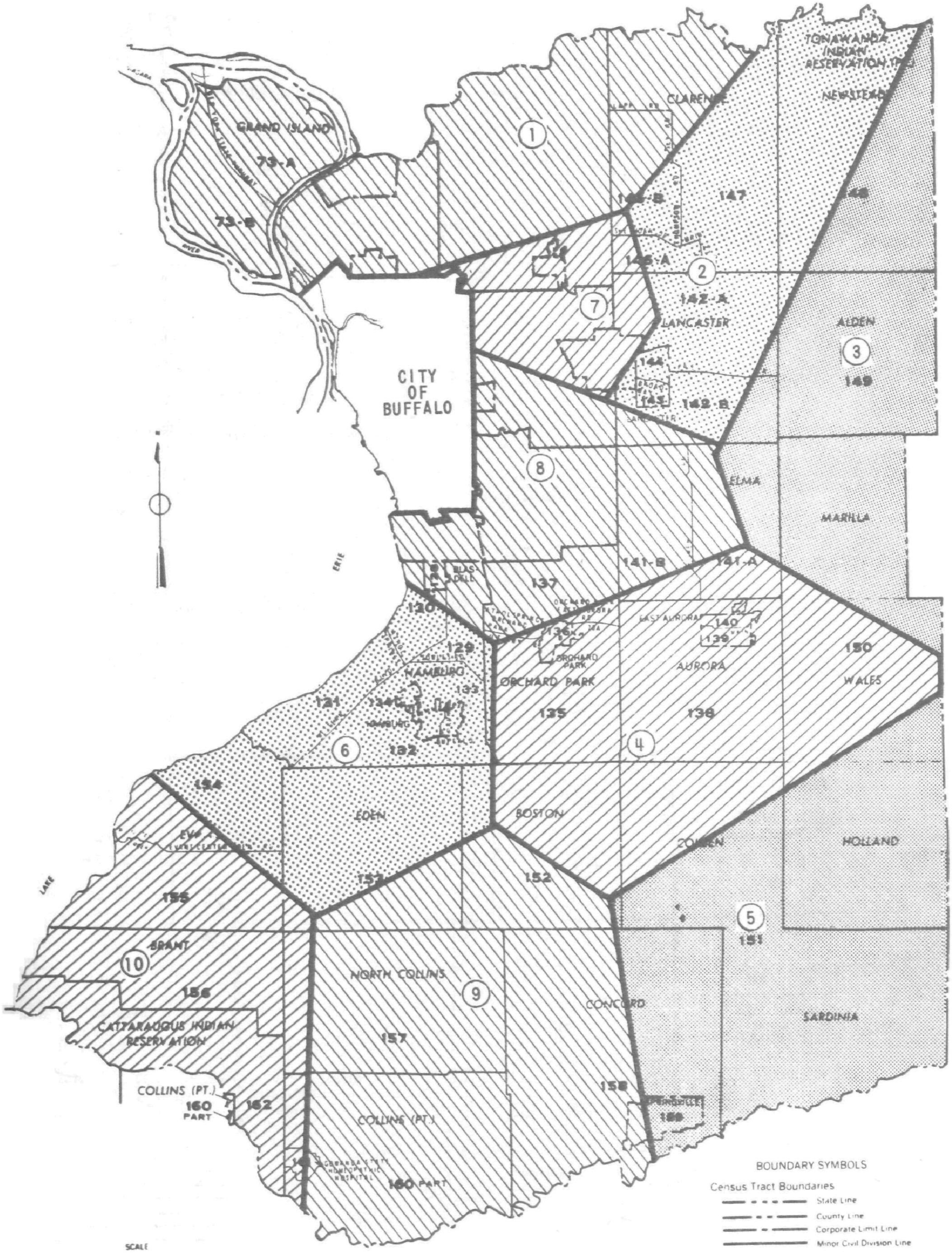

Figure 10 REGIONS OF PREFERENCE AMONG TEN ILLUSTRATIVE LANDFILL SITES, LARGE NUMBER OF INFINITESIMALLY SMALL SOURCE AREAS ASSUMED.

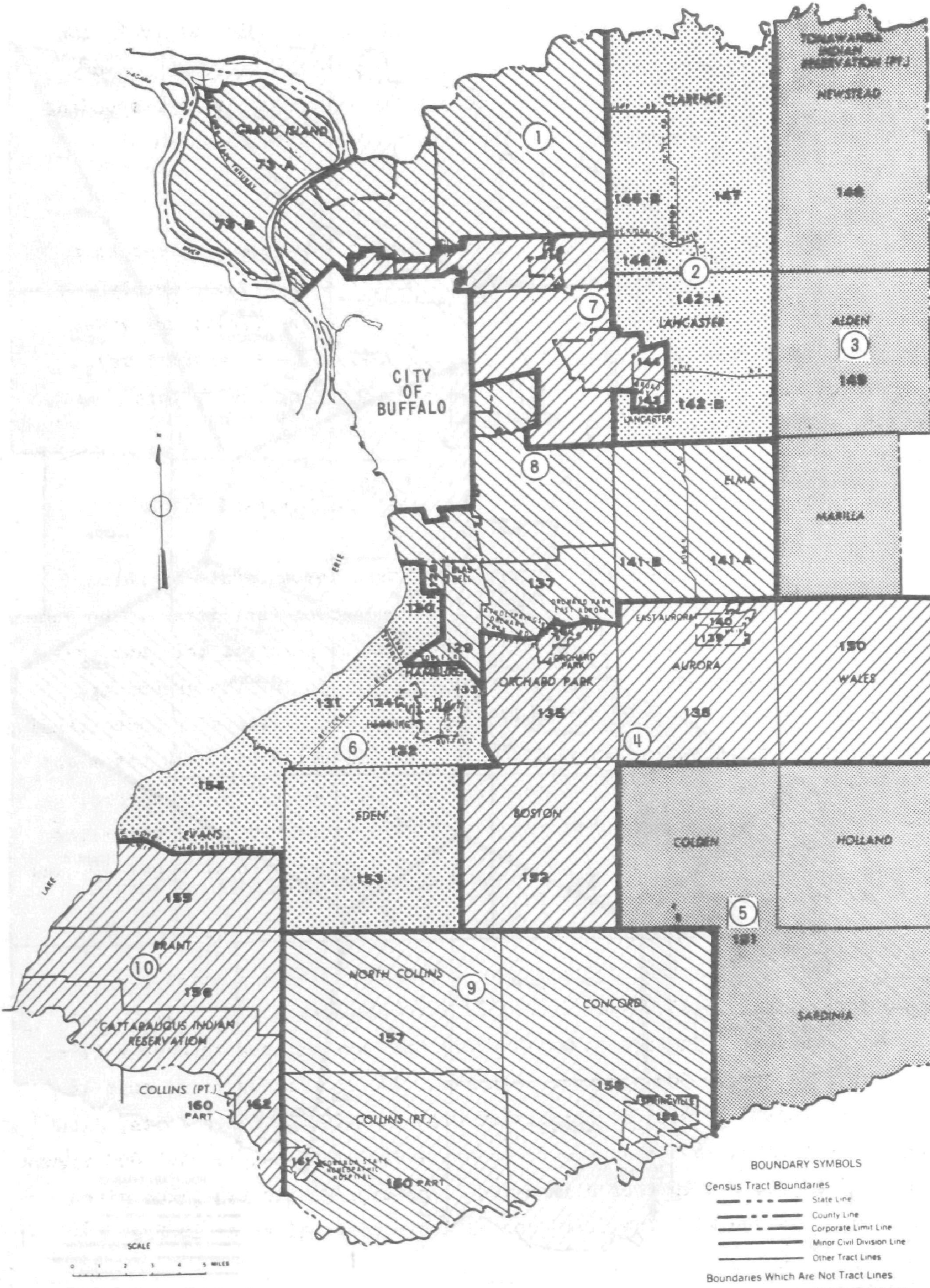

Figure 11 REGIONS OF PREFERENCE AMONG TEN ILLUSTRATIVE LANDFILL SITES, SOURCE AREAS REPRESENTED BY CENSUS TRACTS.

and large in number, application of the above argument would result in the service areas indicated in Fig. 10 . However, since the distribution of refuse sources is approximated by the set of discrete sources corresponding to census tracts, the service areas are distorted into those shown in Fig. 11.

It should be emphasized that this result is not equivalent to a recommendation that all these facilities be put into existence, merely that the service areas be as designated if all these facilities are given. With the introduction of fixed costs into the analysis, it is sometimes cheaper to incur increased variable costs by eliminating one or more facilities in order to save even larger fixed costs.

4.2.2.2 The Effect of Fixed Costs on the Choice of Disposal Sites

In Section 4.3 the rationale is given for an analysis which permits a minimum cost choice from among a given set of facilities to be made. In Appendix I the details of a computer model which performs this analysis are given. In the present section the purpose is to lay the groundwork for the succeeding discussion of processing plant installation by understanding what is meant by the given set of landfill facilities and how that set might be arrived at. Therefore as illustrative material the results of several runs of the facility selection computer model are presented here, where the model was applied to the set of landfill facilities depicted in Figs. 10 and 11 under several assumptions regarding fixed costs.

In Figs. 12 and 13, the same set of ten landfill sites are considered, with c_j = \$3.00 per truckload for all sites and c_T = \$2.00 per mile per truckload. In Fig. 12, all facilities are assumed to have a fixed cost amortized at \$20,000 per year. In Fig. 13, the common fixed cost is \$60,000 per year. It will be noted that with the \$20,000 fixed costs, Sites 2 and 5 are eliminated. When the fixed costs are at the higher \$60,000 figure, Sites 3, 9 and 10 are further eliminated. Therefore, with ten sites given as in Fig. 10 , and with the fixed and variable costs given as in Fig. 13,

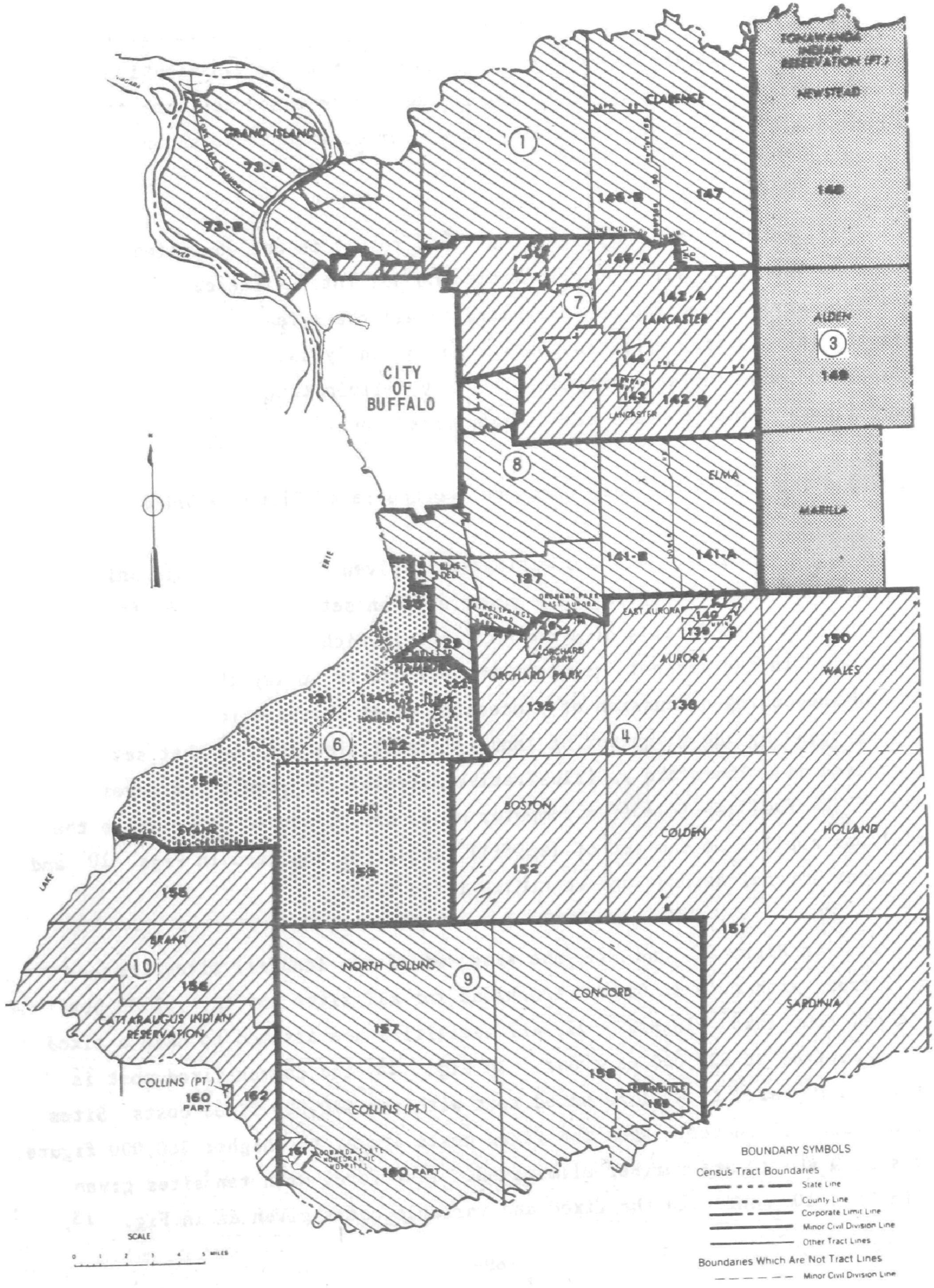

Figure 12 CHOICE AMONG THE LANDFILL SITES OF FIGURE 10, AND THE CORRESPONDING SERVICE AREAS. AMORTIZED FIXED COST OF EACH FACILITY = $20,000 ANNUALLY

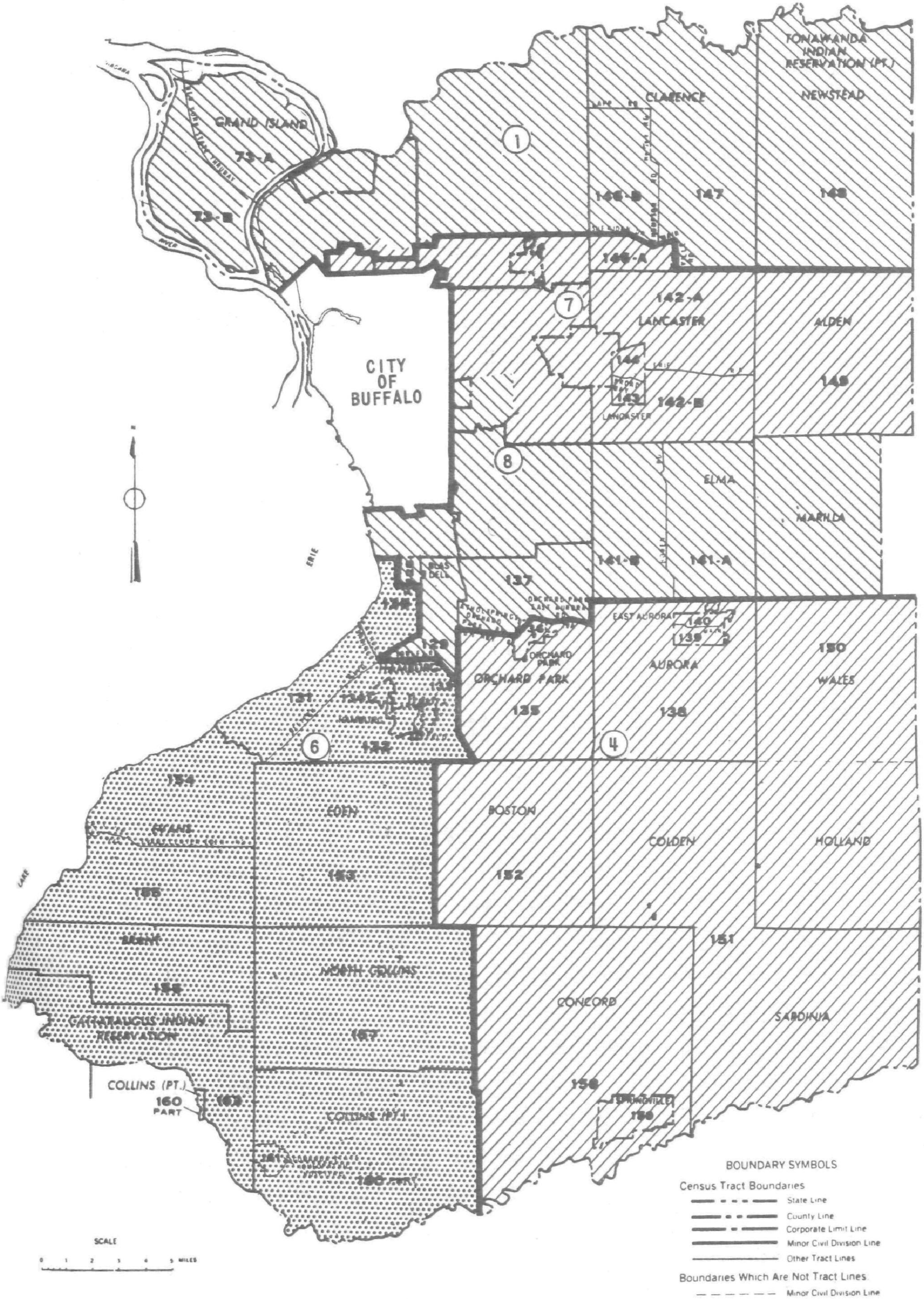

Figure 13 CHOICE AMONG THE LANDFILL SITES OF FIGURE 10, AND THE CORRESPONDING SERVICE AREAS. AMORTIZED FIXED COST OF EACH FACILITY = $60,000 ANNUALLY

there would be only five landfills, located as in the latter figure, and the service areas would be as indicated in the same figure if minimum costs are to be achieved.

This example illustrates the increased undesirability of proximitous landfills as capital costs increase. It also illustrates the interaction of that general rule with population density. For while Sites 5, 9 and 10 cannot be justified because they are too close to Sites 4 and 6, the higher waste generation densities in the northern part of the county allow Sites 1, 7, and 8 all to remain in spite of their being closer together than (say) Site 10 is to Site 6.

The manifestation of the tendency to eliminate proximitous landfills which is specific to this particular example is always to favor the landfills in the populated areas over those in the isolated areas. That is because the fixed costs and disposal costs are all equal, and therefore, the choice is being made essentially on the basis of transportation costs. In a more realistic example, the costs of the rural sites would be lowered to reflect lower acquisition costs and perhaps less taxing operating requirements and there will be more of a tendency for the remote sites to drive out nearby sites in spite of higher transportation costs.

To the extent that higher operating standards for landfills are reflected in higher costs, the tendency to eliminate proximitous landfills reproduces the recent experience of less-populated towns and villages which heretofore had suffered no economic hardship in maintaining separate open-burning dump facilities for each of a myriad of jurisdictions. With the imposition of higher operating standards at the State and County levels, these smaller jurisdictions have been less able to "go it alone" and have either sought consolidated facilities or, at the very least, have turned the disposal problem over to private operators who, by providing service to a large number of jurisdictions, in effect provide consolidation of a different sort. At any rate the economies of scale are realized.

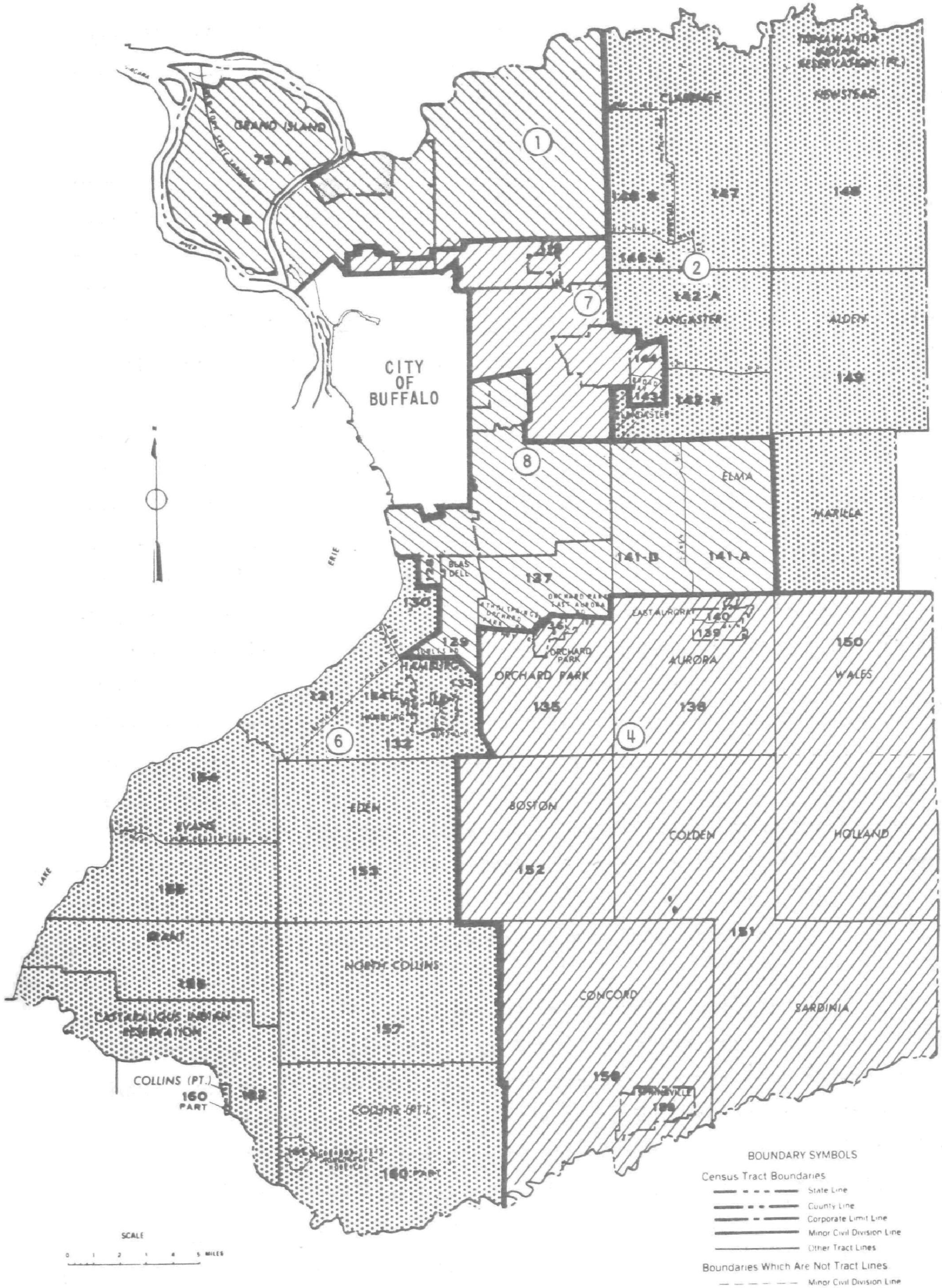

Figure 14 CHOICE AMONG THE LANDFILL SITES OF FIGURE 10, AND THE CORRESPONDING SERVICE AREAS. $A_2 = 0$; $A_1 = A_4 = A_6 = A_7 = A_8 = \$60,000$ ANNUALLY

Finally, one further example is given to show the effect of a site with cost advantages over the other sites. The five sites 1,4,6,7,8 were tried, with fixed costs all equal to $60,000 per year as before, along with Site 2, which now is assumed to have <u>no</u> fixed cost. Variable costs c_j are equal in all six facilities, c_j = \$3. per truckload; c_T = \$2. per mile per truckload as before. It is as if Site 2 is an existing facility, where the others are potential facilities requiring some initial capitalization. The results are given in Fig. 14 , where it will be seen that Site 2 has a substantial service area. Site 2, having been eliminated even in Fig. 12, clearly is at a disadvantage with regard to transportation costs. Here is an example then, where that disadvantage is washed out by a fixed cost advantage to result in making existence of the additional facility economical.

4.2.3 The Decision to Install a Processing Plant - Several Alternative Disposal Sites

Now it is assumed that (J-1) disposal sites have been chosen for the region R, and the latter has been divided into (J-1) subregions R_1, ..., R_{J-1} which represent the service areas of the (J-1) sites. In this section the problem is treated of characterizing those situations where it would be desirable to introduce a processing plant into the region. If introduced, the plant would be located at a specific location (x'_J, y'_J) in in R_1. Under these circumstances, it makes sense to assume that all processing plant products will be disposed of at Disposal Site 1.

All notation used is as defined in previous sections.

Consider now an arbitrary source in R. It must belong to one of the R_j. Clearly, the decision regarding whether processing or direct disposal is preferable at a specific source in R_j involves only the plant and Disposal Site j, for disposal at any other site could only increase the total cost of the disposal system. Thus, for points within R_j, the determination of preference for processing, or for direct disposal, on a unit cost basis, is much like the original problem of determining the region of preference for processing, with only one alternative disposal site.

The only difference is that for sources in R_j with $j \neq 1$, processed refuse is taken to a different disposal site (Site 1) than nonprocessed refuse (Site j). Instead of $c_J = a_J + b_J = a_J + c_P + p\,(c'_T d + c_{Dj})$ for each $j \neq 1$, as would be implied by direct analogy with the case of one alternative disposal site, one has $c_J = a_J + b_J = a_J + c_P + p(c'_T d + c_{D1})$ no matter which disposal site is of interest. Here, $d = \sqrt{(x'_j - x'_J)^2 + (y'_j - y'_J)^2}$; note also that $c_j = a_j + b_j = a_j + c_{Dj}$ is required for determining preference between Disposal Site j and potential Processing Plant J.

Specifically, for Source i located within R_j the region of preference for processing is R_{Jj} which is the set of all sources i in R_j such that

$$c_T\,[d_{iJ} - d_{ij}] \leqq c_j - c_J$$

where d_{iJ} and d_{ij} represent the distances from i to the processing plant site and to Disposal Site j, respectively. In other words, suppose the analysis of Section 4.2.1 were performed using Site j as the single site, and using the revised c_J instead of the original, and suppose that as the result of that analysis the region of preference for processing over direct disposal at Site j were determined. Let R'_{Jj} be that region. Then the desired region R_{Jj} of points within R_j where processing is preferred to direct disposal at Site j (hence preferred to direct disposal at any other site) is merely $R_{Jj} = R'_{Jj} \cap R_j$. The region $R_j - R_{Jj}$ is the region where direct disposal at Site j is preferred both to processing and to direct disposal at any other site.

It follows that the region R is partitioned into the following sets, which intersect only at their boundaries: $R_J = R_{J1} \cup \ldots \cup R_{J,J-1}$ = the set of points in R where processing is preferred, and the (J-1) sets $R_j - R_{Jj}$ where direct disposal at the various disposal sites, without processing, is preferred. Consider the disposal system in which all refuse originating in R_J is processed before disposal (at Site 1) and all refuse originating in $R_j - R_{Jj}$ is delivered to disposal Site j for disposal without processing. If R_J is empty, no processing is performed at all in R and the cost C of the system is the constant value L, where

$$L = \sum_{j=1}^{J-1} A_j + \sum_{j=1}^{J-1} \sum_{R_j} [c_T d_{ij} + c_j]\, q_i$$

If R_J is non-empty, the cost of this system is

$$C = \sum_{j=1}^{J} A_j + \sum_{j=1}^{J-1} \sum_{R_j - R_{Jj}} [c_T d_{ij} + c_j] q_i + \sum_{R_j} [c_T d_{iJ} + c_J]\, q_i$$

$$= L + A_J + \sum_{j=1}^{J-1} \sum_{R_{Jj}} [c_T (d_{iJ} - d_{ij}) + (c_J - c_j)]\, q_i$$

Note that the square-bracketed quantity in the summand is negative over the interior of R_{Jj}. Therefore, if it is assumed that the fixed cost A_J of the processing plant is incurred, it follows by definition of the R_j's and by the argument used previously for the case J=2 that any other partition of R into areas to be served by the plant and by the respective disposal sites could not produce a smaller cost.

It follows that the given system is the minimum cost system, as in the case J=2, (i.e. one alternative disposal site) if

C(system with no processing) $\geq$ C(system where processing is performed in R_j)

Thus the minimum cost system employs +processing for refuse originating in R_J whenever

$$\sum_{j=1}^{J-1} \sum_{R_{Jj}} [c_T (d_{ij} - d_{iJ}) + (c_j - c_J)]\, q_i \geq A_J$$

If the left hand side $< A_J$, then processing is not introduced.

The square-bracketed quantity in the summation is positive in R_{Jj}, and it is clear that processing will be attractive only if refuse quantities are high within R_J. This is consistent with the general practice of adopting incineration only for areas of high population density.

It does <u>not</u> necessarily follow that the most economical system is the one which has the incinerator location at the point of highest population concentration, or of the highest concentration of solid waste sources. This is because the fixed cost A_J must depend on the location of the plant. In particular, acquisition of sufficient property within the area of highest solid waste source concentration can involve extremely high fixed costs relative to another location for the plant within an area of lower concentration.

This can be stated succintly as follows: Let the left hand side of the preceding inequality be denoted S. Then the cost of the disposal system may be written

$$C = L - (S - A_J) \text{ when } S \geq A_J$$
$$= L \quad \text{otherwise}$$

The minimum cost system is not the one with the greatest S, but the one which maximizes $(S-A_J)$. The idea of the preceding paragraph is that one can conceivably gain in S by use of a location right in the center of population or waste source density, but incur an A_J that is so much larger that the difference $(S-A_J)$ is small.

As illustrations of analyses which can be performed using this model, consider the following:

1. The example illustrated by Figure 7 could be extended to the case where the alternative is not one disposal site to the east, but several sites surrounding the city. It might then be expected that the directional effect of the single disposal site would be removed, and even though the Central Business District might not be the best location for the incinerator due to prohibitive acquisition costs (or the cost of operating with minimal deleterious effects in that neighborhood) some location other than the edge of the city might be best.

2. A similar analysis could be run with constants adjusted to reflect truck transfer operations. The output could be combined with data from the incinerator analysis in order to determine those combinations of distances and

costs which indicate incinerator operation, those which indicate transfer-landfill operations, and those which indicate no processing at all.

3. An acceptable configuration of landfill sites could be chosen to serve the non-urban county, and the desirability of introducing processing into the most (i.e. excluding Buffalo) densely populated part of the county could be examined under various assumptions regarding processing costs and processing ratios p.

4.3 A Static Model for Choosing Among Several Processing and Disposal Facilities

4.3.1 General Description

The approach described in Subsection 4.2 is easily extended to cover a broader class of problems regarding facility choice. A "facility" is either a processing plant (e.g., incinerator, truck transfer station) or a disposal site (i.e, a sanitary landfill).

There are J facilities under consideration, indexed by j, $1 \leq j \leq J$. Solid waste generation is approximated by point sources corresponding, typically, to census tracts, collection districts, or other sectors within the region as a whole. There are I sectors, indexed by i, $1 \leq i \leq I$. The quantity of refuse originating in i is q_i. As in the preceding Sections, each facility j has associated with it a fixed cost A_j and a variable cost c_j, where $c_j = a_j + b_j$ with a_j being a cost per unit of increasing the capacity of the facility one more unit, and b_j is the unit operating cost. The cost of transportation of a unit quantity of refuse delivered to facilities in collection vehicles is c_T per mile. The distance d_{ij} is the distance from Source i to Facility j. And here we define the new symbol k_{ij} = total variable cost per unit of processing and/or disposal of waste generated at i, if i is in the service area of Facility j.

In the previous discussion, either J consisted of all disposal sites or there was only one processing plant considered. In the latter case, discussion centered around the processing plant. Here the more general problem is addressed of specification of a logical procedure for determining which of a set of facilities to establish, and the service areas corresponding to the facilities in the chosen set. In particular, choice can be made from among a selection of processing plants and a selection of disposal sites. The procedure is amenable to computer processing, and a FORTRAN program is given in Appendix I for finding the collection of facilities, and the service area assigned to each facility, which will (process and) dispose of the solid wastes of the region with minimum cost.

Broadly speaking, the number, type, and location of facilities is specified, and the minimum cost selection is made from among the given collection. For each facility j selected, the service area R_j is obtained, which is the set of sources i serviced by j. The capacity $Q_j = \sum_{R_j} q_i$ of Facility j is determined by the model; the amortized capital cost per time period, of providing a facility of that capacity (per time period) is given by $A_j + a_j Q_j$, also determined by the model.

If non-empty regions of preference $R_1, \ldots, R_J$ are obtained by comparing costs k_{ij} as in Section 4.2.2, the variable cost portion of total cost will be minimized, by use of that set and by use of the service areas implied by $R_1, \ldots, R_J$, over any subset of those facilities. This however does <u>not</u> minimize <u>total</u> cost, since by eliminating a facility, and reassigning the i's within its service area to other facilities, the resultant increase in variable costs can possibly be more than offset by saving the fixed cost of the facility eliminated.

The problem can be phrased as follows. To each source sector i assign exactly one facility j(i). Let F = [j | j=j(i) for at least one i].

<u>PROBLEM</u>: Assign to each source i one facility j(i) so as to minimize

$$\sum_{F} A_j + \sum_{i=1}^{I} k_{i,j(i)} q_i$$

Stated in this way, where it is implied that the constants k_{ij} are fixed beforehand, the problem may be solved by special integer-programming techniques known as zero-one integer programming. In the present context, having all constants k_{ij} fixed beforehand is equivalent to predetermining a disposal site destination for the output of each processing plant in the problem. Since cost minimization can possibly involve elimination of one of the disposal sites from the system, this assumption can be troublesome. Since there are some problems of interest which do not involve processing questions, and since it is realistic in other problems to predetermine landfill destinations for the processing output which are not included among the disposal facility choices (e.g., certain landfills are for incinerator residue alone) the fixed k_{ij} assumption does not necessarily render useless any techniques based on that assumption.

It would be better not to be bothered by that assumption, however, and for other reasons as well as this one, a technique was developed which did not require that all processing plants be preassigned a disposal site to receive its output. Assume for the moment that the k_{ij} are fixed beforehand. Note that of J potential facilities, there are 2^J-1 possible selections. For example, of the four facilities A, B, C, D, there are 15 possible selections of facilities:

	A and B		
A alone	A and C	A, B and C	
B alone	A and D	A, B and D	
C alone	B and C	A, C and D	All of A, B, C, D
D alone	B and D	B, C and D	
	C and D		

Given any individual selection, the minimum cost under that selection is achieved by assigning to each i that facility, from among those in the selection, which minimizes k_{ij}. The minimum cost over all selections is therefore achievable by a systematic comparison of the costs associated with each of the 2^J-1

possible selections. The objective of the zero-one (and in fact all) integer programming techniques is to circumvent the need to examine all (2^J-1) selections making a number of tests on the array of k_{ij}-values. Often, entire sets of selections (e.g., all selections which include a certain facility) can be eliminated if the collection of k_{ij}'s display various properties. For example: as usual let R_j be the set of all sources i such that $\min_{1\leq h\leq J} k_{ih}=k_{ij}$, i.e., k_{ij} is the least of $k_{i1},\ldots, k_{iJ}$ for those i in R_j. For each i in R_j determine the index j'(i) associated with the next best k_{ij} available for that i. Then if $\sum_{R_j} (k_{ij'(i)}-k_{ij})q_i \leq A_j$ (i.e. the variable cost penalty incurred by letting each i be served by its j'(i) rather than by j is smaller than the fixed cost of j) then clearly Facility j can be eliminated from consideration. By performing a number of tests of this type the number of selections actually examined can be cut down considerably. However, if the number of facilities is moderate, the amount of testing itself represents a considerable amount of effort compared with straightforward evaluation of all possible selections. The approach of reviewing all (2^J-1) possible selections in a routine fashion appears to be little less efficient, if at all, for the cases with k_{ij}'s fixed beforehand. But it offers an additional advantage in not requiring that disposal sites be assigned to processing plants before the analysis begins.

For the assumption that k_{ij} constants are all determined beforehand is equivalent to saying that for all processing plants the operating costs per unit quantity are

$$b_j = c_p(j)+[c'_T d'_j + c'_{Dj}]$$

similar to Subsection 4.2.1, where

$c_p(j)$	=	cost of processing per unit quantity of input
p_j	=	reduction or conversion factor
	=	[output in output units]/[input in input units]
c'_T	=	cost per mile of hauling a unit quantity of output
d'_j	=	distance to (predetermined) point of disposal of output
c'_{Dj}	=	cost per unit quantity for disposal of output at the (predetermined) disposal site assigned to Facility j.

If that assumption is not made, and b_j can change depending on the trial selection of facilities because under a given selection a more advantageous disposal site may be available for the output of processing Facility j, then the expression for b_j must be rewritten for each trial selection. Assuming that under a specific trial selection the destination of the output of Facility j is disposal Facility j',

$$b_j = c_P(j) + p_j \, [c_T' d'(j,j') + c_D(j')]$$

where d'(j,j') is the distance between the two facilities j and j', and $C_D(j')$ is the unit cost of disposal at Facility j'. Under any selection, the disposal site assigned to processing Facility j corresponds to the index j' which minimizes the bracketed quantity over all disposal sites in the given selection.

A straightforward series of steps can readily be inferred from the discussion which are amenable to digital computer programming, and which lead to a minimum cost selection of facilities and service area assignments for each of the selected facilities. A computer routine which performs these steps is given in Appendix I. The program is based on a subroutine, described in Appendix H, which allows all of the 2^J-1 possible selections out of J facilities to be generated in turn.

For each selection, the minimum cost configuration of service areas is found, and the corresponding cost is computed. This quantity is compared with the lowest previous cost found in the selections reviewed prior to the current one. If the cost achieved with the current selection is less than or equal to the best previous one, the facility selection, configuration of service areas, and cost achieved are printed out. If the cost achieved with the current selection has been bettered by a previous selection, the routine continues with the next selection supplied by the selection generating subroutine. After all possible selections have been reviewed, the last selection printed out (or the last several if there are any ties) is the minimum cost selection.

Steps taken by the routine with regard to each of the (2^J-1) selections are as follows:

1. Does the selection contain any disposal sites? (If so, go on to Step 2; if not, the selection is not a feasible selection and the program skips the rest of these steps and calls the selection generating subroutine for the next selection.)

2. Does the selection contain any processing plants? (If not, go directly to Step 4.)

3. For each processing plant (say Facility j) compare the quantities $[c_T'd'(j,h) + c_D(h)]$ where h runs over all disposal sites in the selection. Let the minimizing h be designated j'. Facility j' is the disposal site assigned to receive the output of Facility j. Compute $b_j = c_P(j) + p_j[c_T'd'(j,j') + c_D(j')]$ for each processing plant, and $c_j = a_j+b_j$.

4. For each disposal site (say Facility j), let $b_j = c_D(j)$ and compute $c_j = a_j+b_j$.

5. For each source (say Source i) compare the quantities $k_{ij} = [c_Td_{ij}+c_j]$ where j runs over all facilities in the selection. Let the minimizing j be designated j(i). Facility j(i) is the facility whose service area contains Source i. If there are two or more j's which determine the minimum k_{ij}, record this fact, but let j(i) = the smallest of the minimizing indexes.

6. Compute $\sum A_j + \sum_{i=1}^{I} k_{i,j(i)}q_i$, where the first sum is over all facilities in the selection. This is the minimum cost possible with the current selection of facilities; this quantity is compared with the minimum costs achieved with the other previously generated selections.

It should be noted that for an arbitrary Facility j, the service area under any selection is the set of sources i such that j(i)=i. It should further be noted that the quantity $Q_j = \sum q_i$, where the sum is over all sources in the service area of j under the minimum cost selection, determines the quantity of unprocessed refuse to be received by Facility j in each time period. There are no capacity figures set as constraints on facility sizes in this model, and the quantities Q_j are used as indicators of desirable facility sizes within a planning context.

4.3.2 Distance Data Required

In order to compute the required constants k_{ij} the distances d_{ij} corresponding to each pair (i,j) are required, among other data. With regard to the d_{ij}'s, road distances rather than straight-line distances should be given. Since it is extremely tedious, and possibly not too fruitful to provide actual road distances between each source and each facility location appearing on any run of the program, an estimate of the form

$$[\text{road distance}] = \alpha \cdot [\text{straight line distance}]$$

is used, with evidently satisfactory results. The requirement is for IJ distances, so that use of the estimate eliminates need for a considerable amount of input information. The distances can be computed if one includes among the inputs the locations of all facilities on some coordinate system. Besides the IJ distances d_{ij}, there will also be need for some of the $\binom{J}{2}$ distances between pairs of facilities; these are represented by the distances d'(j) and d'(j,j') of the foregoing text. It should be noted that indications exist of the size of the factor α. Results quoted in [Ref. 35] specify $\alpha = 1.2$. Some trials made locally suggested that a higher value, perhaps 1.3, is appropriate, and this factor was built into all C_T-values used on runs of the program.

4.3.3 Uses of the Static Model

Straightforward uses of the model described above readily present themselves, for example, answering questions regarding present needs for facilities of various types in Erie County. Specifically, one can answer questions of the following sort:

- Given use of a landfill facility outside the city (at a specific location) does it make sense to replace the Buffalo East Side Incinerator?

- If landfill of unprocessed refuse is preferable to incineration, should a transfer station be used?

- Given the existence of the Lancaster Landfill, does it make sense to install a county operated landfill at the proposed site (behind the Erie County Penitentiary)?

Using the model over well designed series of runs, questions related to the above can be answered, which begin to display general principles to be applied in system design. Examples of such series are:

- With fixed incinerator location, and fixed cost parameters, vary the landfill location from run to run in order to determine the minimum distance for such an incinerator to be economical.

- Run through a similar series with parameters reflecting transfer station operations, to determine the distances over which such operations would be economical.

- In the above situations change cost relationships or process reduction parameters from run to run to see how the distances for economical operations under incineration, transfer and direct landfill are affected by costs or the process input-output relationship.

- With fixed transportation and landfill costs, vary landfill locations over the county and distance between landfills from run to run in order to determine how closely landfills can economically be placed as a function of various population density levels.

4.4 Application of the Model to Balance Costs Against Various Levels of Deleterious Effects of Solid Waste

In Section 4.1, it was suggested that the minimum cost approach was basic to the idea of allowing the difference in costs between two system configurations to be identified with the levels of service inherent in the two configurations. In effect, what was said was that the cost differences among systems configured differently were attributable to differences in service rendered by the different systems as well as inefficient use of the facilities available under any configuration (e.g. improperly defined service areas from the point of view of minimum system costs). By use of a minimum cost concept as in the facility choice model described above, the portion of the cost differential attributable to inefficiencies is minimized and the differentials can therefore be interpreted as reflecting the costs of different levels or types of service.

This is not the same as quantifying deleterious effects of solid wastes in the sense of measuring the loss to the community due to those deleterious effects in dollar terms (e.g. increased cleaning and painting costs due to incinerator effluents in the air). Nor does it provide a measure of dis-service or level of bad effects on some non-monetary value scale such as has been developed by Aerojet-General [Ref. 11]. It does, however, offer an analytical means whereby regional decision makers can weigh costs against benefits of regional system configurations with stated operational characteristics. Given two system configurations displaying characteristics (including bad effects of solid wastes) between which decision makers at the regional level have no marked preference, the cheapest configuration will presumably be preferred. If the characteristics of one system configuration are preferred over those of a second, it is the task of the decision makers to decide whether the difference in costs, which is the price of the preferred configuration as compared with the other, is acceptably low. This is good systems planning procedure, and any analysis which advances the capability for making this decision is presumably good systems analysis.

This argument bears on development of a facility choice model in the following way. The cost relationships introduced in previous sections, namely

$$\text{Cost per time unit of Facility } j = A_j + c_j Q_j$$

and the operational parameters used to determine the c_j's themselves, implicitly reflect quality of operations and levels of bad effects of solid wastes and solid wastes processing and disposal practices. Just as series of runs were contemplated over which locations and types of facilities were varied, one can also think of series within which quality of operations is changed from run to run.

For example, suppose for an incinerator facility, say Facility j, three sets of operational parameters are considered which will be designated as GOOD, BETTER, and EXCELLENT modes of operations. Suppose that these designations represent quality differences in terms of volume reduction and quality of residue as well as amounts of particulate and gaseous effluents. <u>Specific</u> plant descriptions designed to characterize the three quality designations will lead to estimates of volume reduction, quality of residue, and amounts of particulate and gaseous effluents for the three modes of operations, as a function of level of operations in terms of average quantity incinerated per unit time. From these, reduction factor values corresponding to the three modes, which can be designed $p_j^{(G)}$, $p_j^{(B)}$, $p_j^{(E)}$ respectively, can be derived for use within minimum cost computations. In addition, associated with each of the designations there will be a pair of cost constants,

$A_j^{(G)}$, $c_j^{(G)}$ to reflect GOOD operations

$A_j^{(B)}$, $c_j^{(B)}$ to reflect BETTER operations

$A_j^{(E)}$, $c_j^{(E)}$ to reflect EXCELLENT operations.

A series of runs in which the various sets of constants are changed from run to run will result in the following:

a. The amounts of residue under the three modes will differ. Because of this, the transportation costs will differ and the landfill requirements for disposal of residue will differ under the three modes.

b. The minimum cost system configurations under the three modes will differ. This is a reflection of the different amounts of residue and the different transportation costs as well as the differences among the G, B, and E sets of fixed and variable costs. In general, even where the incinerator is economically justified under all three modes of operation, the average quantity Q_j of refuse to be incinerated each unit time period will be different among the three modes, as will the service area assignments.

c. The minimum costs themselves under the three modes will differ. These different costs are more than the mere statement of the total costs

$$A_j^{(G)} + c_j^{(G)} Q_j^{(G)},\ A_j^{(B)} + c_j^{(B)} Q_j^{(B)},\ A_j^{(E)} + c_j^{(E)} Q_j^{(E)}$$

per time period to build and operate Facility j under the G, B, and E modes respectively. Because of the system relationships involved (more incinerated implying more residue, implying higher transportation costs and required landfill space, implying higher landfill costs, and so on) the cost differentials under the three modes of operations refer to the total system cost of the minimum cost systems derived under the three sets of input data.

d. From the quantities $Q_j^{(G)}$, $Q_j^{(B)}$, $Q_j^{(E)}$ obtained under the respective modes, and from detailed process descriptions of incinerators representative of tne three modes of operation, calculations can be made of the air pollutant emissions to be expected under the three modes. These can be expected to differ markedly. This data, together with the landfill space requirements and knowledge of the locations involved, affords the decision maker a picture of relative bad effects of solid waste under the three modes. The different bad effects levels can be compared by the decision maker and weighed against the different costs involved in bringing them about to see if potential improvements are worth the additional cost.

It should be realized that this approach does not depend on there being exactly three modes or any other specific number, and that the "G-B-E" classification was used above merely for illustrative purposes. In practice, something akin to the "G-B-E" definition of modes of operations might be adapted from a facility checklist and scoring technique such as has been under development by the U.S. Public Health Service. Or, the modes of operations might reflect measurable engineering performance rather than a qualitative categorization of operations. In fact, the modes might reflect a performance measure which is in concept a continuous parameter, for example incinerators classified according to the percent of pollutants the anti-pollution devices are designed to remove.

4.5 Experience with the Facility Selection Model

This study was methodological, and the primary concerns with the facility selection static model were whether it would produce the types of answers it was expected to, and whether it could do so within reasonable limitations on time, effort, and expense. Performance of actual system analyses were of interest only in the sense of providing a real context for development of the tool. Moreover, it was believed that extensive running of the program as applied to current Erie County problems would be inappropriate without a credible collection of submodels relating costs and operations of facilities of various types. This point is elaborated upon in Section 4.6.

In this short section some general comments will be made on the operation of the program. Then the runs made thus far with the program will be enumerated, and those not previously presented in the foregoing discussion will be elaborated upon.

The computer program for the facilities choice static model performs its tasks with brute force rather than guile. With only a superficial examination it is easy to see that it is wasteful of steps and storage; it probably wastes computer time as well. No effort at all has been expended on optimizing this program in any way. It should also be mentioned that the program embodies two features which work against short running times: (1) if any source can fall into one of several service areas without enlarging the minimum cost configuration, this is noted in the output, (2) if more than one selection of facilities exists which yields the minimum cost over all selections, the equality is noted in the output and the service area assignments associated with each of the selections are each printed out. The figures employed during the computation are in "floating point" form which makes detection of costs which are <u>exactly</u> equal a non-trivial task.

In spite of all this, the computer times experienced with the program have been quite satisfactory. All runs have had the number of facilities J no more than ten. With J=10, there are $2^{10} - 1 = 1023$ possible selections to cycle through. An early test run using J = 10 and the number of sources I = 20 was completed in 25 seconds (of which approximately half was devoted to loading and operating system steps) on the IBM 360/65 at CAL. A more recent run (which was used to derive Fig. 12) had I = 110, the number of sources in Erie County excluding Buffalo, and J = 10. Independent of compiling, loading, and other operating system steps, the run was completed in 94 seconds. Since the program was designed for testing concepts and for development of a characterization of good system configurations, it is not necessary that this program be capable of reproducing the entire existing County "system" which has over 30 separate facilities. Rather, it is expected that the expressed purpose can be best served by studies in which J is not too large; for such studies the computer times are certainly within the tolerable range.

To date, the following runs have been made, over and above runs completed during the debugging stage.

1. Forty runs, on data from the City of Buffalo, used to derive Fig. 7. Results have been discussed in Section 4.2.1.

2. Four runs, on data from Erie County except Buffalo, used to derive Figs. 11-14. Results have been discussed in Section 4.2.2.

3. One run, on data from Erie County except Buffalo, used to illustrate use of the model with a mix of facility types. Discussed in next paragraph.

4. Fourteen runs, on data from the City of Buffalo, used to consider various possibilities for incinerator sites within the City of Buffalo. Discussed several paragraphs farther on.

As already indicated, the first two sets of runs have been discussed elsewhere. The other two will be described right here.

The single run on County data excluding Buffalo had J=5, with three landfills, one incinerator, and one truck transfer station. The landfills were at locations 2, 5, and 10 of Figure 10; from previous runs it was reasonable that this trio would not tend to eliminate one another, and the selection makes sense from the point of view of land availability. The incinerator location was an arbitrary one in the City of Tonawanda, the area of highest waste generation density in Erie County excluding Buffalo. It was selected since it appeared that if there were one area outside Buffalo where incineration might be advantageous, that would be the one. The transfer station was situated at location 6 of Fig. 10; it seemed a likely spot since it is a fair distance from any of the landfills and it is a suburban population center.

The facilities data used on this run was the same as that used in Section 4.2.1 with one exception: where c_2 = 3 \$/truckload as in the former section, $c_5 = c_{10}$ = 6 \$/truckload was used to account for the fact that location 2 is the site of an existing landfill while land in the vicinity of locations 5 and 10 would have to be acquired and developed into landfills, and for the fact that excavation costs at location 2 are minimal since it is the site of a dry bed stone quarry. It is realistic to make $A_2 = 0$. Since the fixed costs associated with the rural landfills are small compared to the processing plants and certainly compared to the total cost, the simplifying assumption $A_5 = A_{10} = 0$ could be safely made. Fixed costs associated with the incinerator and transfer station were amortized at \$60,000 and \$10,000 per year, respectively. (Note again, the capital cost of a facility is not amortized at A_j per year, but at $A_j + a_jQ_j$ per year, where Q_j is the average quantity per year input to the facility.)

The results were that the incinerator is justified while the transfer station is not. It should be noted that the approximate location of 6 has been suggested as the site of a truck transfer station, but only with location 2 as an alternative, not location 10. The incinerator would send its residue to location 2 of the three available in the run; in reality there is a small amount of landfill nearby, reserved for special types of refuse, which makes a better destination, but this is of no particular interest in the present discussion.

This run was the one whose output appears in Appendix I; the selection (1,2,3,4) on the printout refers to sites 2, 5, 10, and the incinerator in Tonawanda, respectively.

The set of 14 runs on City of Buffalo data was for the purpose of investigating whether other locations in the City would be more suitable than the ones actually used. In all runs, it was assumed that the Squaw Island Incinerator (West Side) was a fixture, although its capacity was left to be decided (i.e. operations at current capacity were assumed to cost nothing except operating costs, while expansion to larger capacities would involve additional variable costs). The following general tendencies were found in the data:

1. The minimum cost solution is to expand the West Side Incinerator so it can service all of Buffalo, unless the variable costs per ton at the East Side Incinerator (c_2) and the variable costs per ton at the West Side (c_1) are approximately equal or $c_2 < c_1$. This means that $a_2 + b_2 \leqq a_1 + b_1$ or that $b_2 - b_1 \leqq a_1 - a_2$ for the ES facility to be in the minimum cost choice. Using current practices, which involve use of the landfill adjacent to the WS incinerator to dispose of residue from both incinerators, it should be noted that b_2 contains the cost of an eight mile round trip which b_1 does not; this is approximately \$1.10 per ton of input. So, for example, even if expansion of the WS plant costs on the average of \$1.10 more per ton daily than building an ES plant from scratch, the operating costs at the ES plant would have to be cheaper than at the WS plant in order to be included in the minimum cost choice. This, of course, does not argue that the plant should not be built, because of the "eggs in one basket" argument. If $c_2 > c_1$ and Buffalo <u>does</u> proceed with a new plant, the resultant system cost less the minimum cost (achieved by building enough capacity in the WS plant to handle the whole city) can be considered the cost of insurance against total breakdown of the entire system or the cost of some degree of flexibility of the system.

2. There evidently are no conditions under which more than two incinerators could be economically justified.

3. Of a variety of materially different locations within the City, no location ever beats out the present site of the ES incinerator as the site of a second incinerator except a location in the heart of the central business district, and this can only be done by making fixed cost assumptions for the downtown location which are unrealistically competitive with the ES site. Moreover, the runs were done under the assumption that the downtown site and the ES site would dispose of their residue on the Squaw Island site, near the WS incinerator. As was indicated in Section 4.2.1, if an alternative site east of the city, or in the eastern part of the city, were provided to receive the residue of the ES facility, what preference there is for a central site will be even further lessened. Incidentally, a site sometimes proposed in South Buffalo cannot be economically justified even if the assumption is made that the fixed costs are competitive with those of the ES site. The latter tips the scales unreasonably in favor of the South Buffalo site, since it does not belong to the City and the ES site of course does. The preference of the ES site over the one in South Buffalo is manifest in spite of the fact that it was assumed that on-site disposal of residue would be possible at the South Buffalo facility, if it were built.

4.6 Facility Submodel Requirements

As has been indicated elsewhere, full use of the facility selection model to perform comprehensive system analyses requires submodels of facility operations and costs. Submodels of all facility types which might conceivably be part of the regional system are required, including landfills, incinerators, transfer stations, composting plants, etc. Submodels will also be required of major subtypes, for example "cut-and-cover" landfill operations as distinct from operations where an existing excavation or low in the terrain is filled, or truck transfer stations as distinct from rail transfer stations.

These submodels need not necessarily be complex; in fact the entire preceding discussion rather dictates that they be simple in structure. It is more important that they be valid, and widely accepted as such, within the error tolerances appropriate for the context in which they are used, than it is that they describe the operations in minute detail. It should not be forgotten that the use of these submodels, and of the entire facility selection model, is to aid regional officials working in an area where it is possible to hear arguments at a county agency meeting over whether a new incinerator (with capacity and location thoroughly understood and operating characteristics generally understood) will cost five or ten million dollars!

The following comments will apply to facilities meeting a fixed standard of operations, whether that be good, better, excellent, or conceivably, a low standard. Subsequently, comments will be made on supplying the required data for each of a given set of standards.

With respect to each facility type or major subtype, and given a fixed standard of operations, the requirement is for a description of a typical facility of the given standard, described as a function of the average quantity of refuse per time period that is input to the facility. It is, of course, possible to collect empirical data on facilities of various sizes, but this method is not too fruitful in at least three respects:

1. All facilities of a given size (capacity) are not identical or even similar with regard to anti-pollution control devices or measures, neighborhood land values, quality of structure, etc. Nor, clearly, are all facilities with comparable anti-pollution controls found to have the same capacity. Attempts to cross-classify make the number of items within any cross-classification too small to yield valid generalizations.

2. Descriptive data on existing facilities represent a range of facility construction dates and hence a range of construction and operational practices as well as a changing cost level. Thus it is even difficult to get a picture of present costs from past data, not to mention future costs.

3. New facilities tend to outstrip past facilities in size as well as performance, and extrapolations are necessary to yield estimates based on past data. For example, it is difficult to find data describing operations of incinerators of 1200 tons per day capacity. Likewise it is impossible to find empirical data on incinerators with electrostatic precipitators.

It is more expensive, but better practice to define a set of benchmark operating capacities, and for each capacity have specialists in the design, construction, and operation of facilities of the given type or subtype generate a typical facility of the given capacity and meeting the underlying standard. A description of each facility could be generated therefrom. This description would include:

Acreage Required (Including any Buffer Zones)
Structures Required
Square Feet in each Structure
Administrative Personnel Required
Operating Personnel Required
Dollar Costs of these Personnel
Construction and Installation of Equipment
Dollar Cost of Construction of Equipment
Dollar Cost of Installation of Equipment
Other Equipment, such as Motor Vehicles
Large Items of Maintenance and Frequency
Labor and Materials for Routine Maintenance
Materials Required for Operations

From such a detailed list and current cost data, the cost of a facility in any region and any time period could easily be assessed, if only the dollar items on the list are reviewed periodically and updated with the same expertise as was applied to the original. Moreover, if information is gathered regarding land values in the area of a potential facility, it is easy to convert the "Acreage Required" information into a cost item.

The result is that for each capacity a complete evaluation of capital and operating costs would be available, and this would be based on a facility of known and stated characteristics. Inclusion of other items in the description referring to pollutant emissions, quantities of output material (for processing plants), and landfill capacity used per time period enable the requirements for information on the operating characteristics of the facilities to be satisfied. Plotting costs against capacities, and using some interpolation, one obtains a function of costs vs. capacity for each facility type (and underlying standard of operations).

It is expected that this function will be approximated well by a linear function. There are indications that this is often the case; see, e.g. [Ref. 30]. If it is the case, the required constants A_j, c_j are a natural consequence. If a curvilinear function is required, a piecewise linear approximation to the function can be found; the analysis as has been presented earlier will no longer suffice, but some modification of the model which can handle piecewise linearity would not be difficult to come by. Remembering the argument over five vs. ten million dollars cited earlier, it is believed that considerable progress would result even if linear function approximations were forced onto all cases. In either case, obtaining the basic estimates and deriving the functions would appear desirable.

Now including in system analysis the many standards of operations which are possible for a given facility type requires that the process above be gone through for all quality levels to be included. This requires then, that before going through the steps indicated above, the experts must first agree on a set of levels to investigate. This does not necessarily mean that the effort multiplies by the number of levels to be considered. For example, in designing two incinerators with different air pollution standards for the same type of pollution control device, a completely new plant will not have to be considered for each. Rather one basic plant would be considered, with further effort devoted to the changes necessary to adopt the different device in the second case. This is not double work, e.g. the space required to house and service the furnaces should be the same in both cases.

4.7 Facility Selection as a Sequence of Choices over Time

The approach thus far has been to consider facility selection as a static process, so that, for example, the assumption could be made that the operating level of a facility and its capacity were one and the same. In actuality, this is not the case; and throughout the lifetime of a facility, particularly large processing plants such as incinerators, there will ordinarly be some portion of the capacity of the facility which is unused, since the capacity will have been set in anticipation of future, rather than present needs at the time of its design.

This need to recognize changing population patterns over the region and per capita increases in waste generation, and in addition to recognize the varied ages of existing facilities and that the capacities of the various disposal sites will occur at different times in the future must be met by a facility selection model which treats selection as a dynamic, rather than a static process.

Although the model described above does not explicitly treat decisions over time, it can be used at any stage within a sequence of decisions to make choices for that stage alone. A criterion of goodness of a method of making decisions over time is fundamentally some measure of the closeness which the choices made can be kept to the most desirable possible set of facilities considering each time point individually and independent of the rest. Since the latter choices are deriveable with the model described herein, this static model is of use in developing a concept of good sequential decisions and in evaluating sequences of choices for given time-related spatial distributions of generated refuse.

Considerable time has been spent on this study in an attempt to treat the dynamic problem as a natural extension of the static problem through the application of zero-one integer programming techniques. These efforts were not successful, nor were other efforts to achieve rigorous extremalization of some function reflecting costs over many time periods through use of dynamic programming. In both cases, the difficulty lay in writing conditions which would establish the continuity of service of facilities; in other words, it proved difficult to prevent facilities from dropping out of service for one or more time periods, and then appearing again some time in the future.

Without further experience with the static model, it is difficult to say just how sophisticated a tool one really needs. With running of the static model over a succession of time periods independently, it might prove that patterns shift slowly enough to prevent such service discontinuities from occurring even with no explicit side condition which forbids it. If that should be the case, it would be inappropriate to devote a great amount of further effort in search of a true optimization technique.

As an interim, practicable approach, the following intuitively suggestive procedure is proposed:

1. Discretize the total time period under consideration into a succession of equal time intervals. An elemental duration of from two to five years may represent a suitable compromise between the opposing desires of few intervals and relative constancy within a single interval.

2. Minimize total cost (fixed plus operating) incurred at each time interval, sequentially; at each step use conditions determined by previous steps. The static optimization model may be applied here.

3. Introduce a global optimality criterion. One that seems both reasonable and simple is to minimize the sum of per capita total costs over all the time intervals of the period under consideration. (Discounting of future expenditures does not appear to be appropriate here as the funds are not available in advance, being basically derived from current tax revenues.) This criterion recognizes that minimizing total costs can place an undue burden on the population of an area with high growth potential before the bulk of the population arrives to foot the bill.

4. If in the solution obtained in Step 2 a given collection district or a processing plant output has the <u>same</u> destination over all of the time intervals, then that destination is maintained for our final solution. If on the other hand, the destination is first D_0, changing to D_1 at time interval t_1, changing to D_2 at $t_2, \ldots$, and finally to D_n at t_n (from thence to end to total period), then in our final solution this sequence of destinations is still maintained (for the given collection district or processing plant output) with the exception that $t_1, t_2, \ldots, t_n$ are permitted to vary over all possible values (but still maintaining the given order). Such variations are permitted to take place simultaneously for all collection districts or processing plant outputs which have non-constant destinations in Step 2, and that combination of altered transition times which satisfies our global optimality criterion of Step 3 becomes our final solution.

If for example, we have a problem with ten time intervals and five cases of <u>single</u> destination transition during total period, then total number of combinations is 10^5 and the brute force method of complete exhaustion is probably feasible. If, however, more cases and more destination transitions per case occur, then programming procedures of greater efficiency would probably have to be found, or there would then be justification for continuing to look for a high-powered optimization technique.

A specific set of assumptions and format for structuring the problem according to this approach is presented in Appendix J.

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APPENDIX A: THE BUFFALO STANDARD METROPOLITAN STATISTICAL AREA (SMSA)

A.1 Introduction

The material contained in Appendix A is provided in order to present some of the salient factors which have a direct bearing on the generation of solid waste and some of the pertinent factors to be incorporated in examining the solid waste management problems of the Buffalo SMSA. Although a comprehensive description of this region would entail a huge amount of material and data, all of which has some relevance to solid waste handling problems, it is possible to distill from this extensive information a more limited description which is germane as well as useful to an examination and analysis of solid waste handling.

The appendix is organized in the following subjects

- Geologic and geographic profile of Erie and Niagara counties
- Local government and population distribution within the two counties
- Economic profile of the Buffalo SMSA

Much of the material to be presented has been obtained through summarizing pertinent papers which were published within "Urban Characteristics of the Niagara Frontier: An Inventory," State University of New York at Buffalo 1964 (Ref. 16).

In a sense, this Appendix can also be viewed as a restrictive inventory which is related to our current project. Although much of the information has not been used directly within the study, it has provided some significant insights into some of the realities confronting planners and decision-makers, e.g., the large number of political, independent subdivisions; the climactic factors which may affect particular solid waste handling solutions; the variety and quantity of solid waste which is generated by business and industry activity, etc. It is only through a broad understanding and appreciation of the composition of the specific region that meaningful solid waste analysis and implementation can be performed which hopefully will have relevance for the future.

A.2 Geologic and Geographic Profile of Erie and Niagara Counties

A.2.1 Geological Highlights

The Buffalo SMSA (also referred to as the Niagara Frontier), comprising the Counties of Erie and Niagara in the State of New York lies between north latitude 40°28' and 43°23' and west longitude 78°29' and 78°03'. The area is bounded on the north by Lake Ontario, on the west by Lake Erie and the Niagara River, and on the south by Cattaraugus Creek. The land area of the two county region is 1587 square miles with a maximum north-south dimension of approximately 67 miles and a maximum east-west dimension of approximately 37 miles. Erie and Niagara Counties, and the natural boundaries of this region are shown on Figure A.1.

Topographically Erie and Niagara Counties are divided into four distinct areas separated by three escarpments. The four areas are the Ontario, Tonawanda-Chippewa, and Erie Plains, and the northern edge of the Allegheny Plateau. The Niagara escarpment, the Onondaga escarpment, and the Portage escarpment separate the four areas into a terrace form pattern which slopes northward from an elevation of about 2000 feet on the Allegheny Plateau to 246 feet at Lake Ontario. A geologic cross section from the northern portion of Niagara County to the southern portion of Erie County, illustrating the following brief topographic description as shown on Fig. A.2.

The Ontario Plain comprising the northern portion of Niagara County, is bounded on the north by Lake Ontario and on the south by the Niagara escarpment. The average elevation of this plain is 200 feet. The Tonawanda-Chippewa Plain separated from the Ontario Plain to the north by the Niagara escarpment has an average elevation of about 600 feet. The surface of the plain is essentially

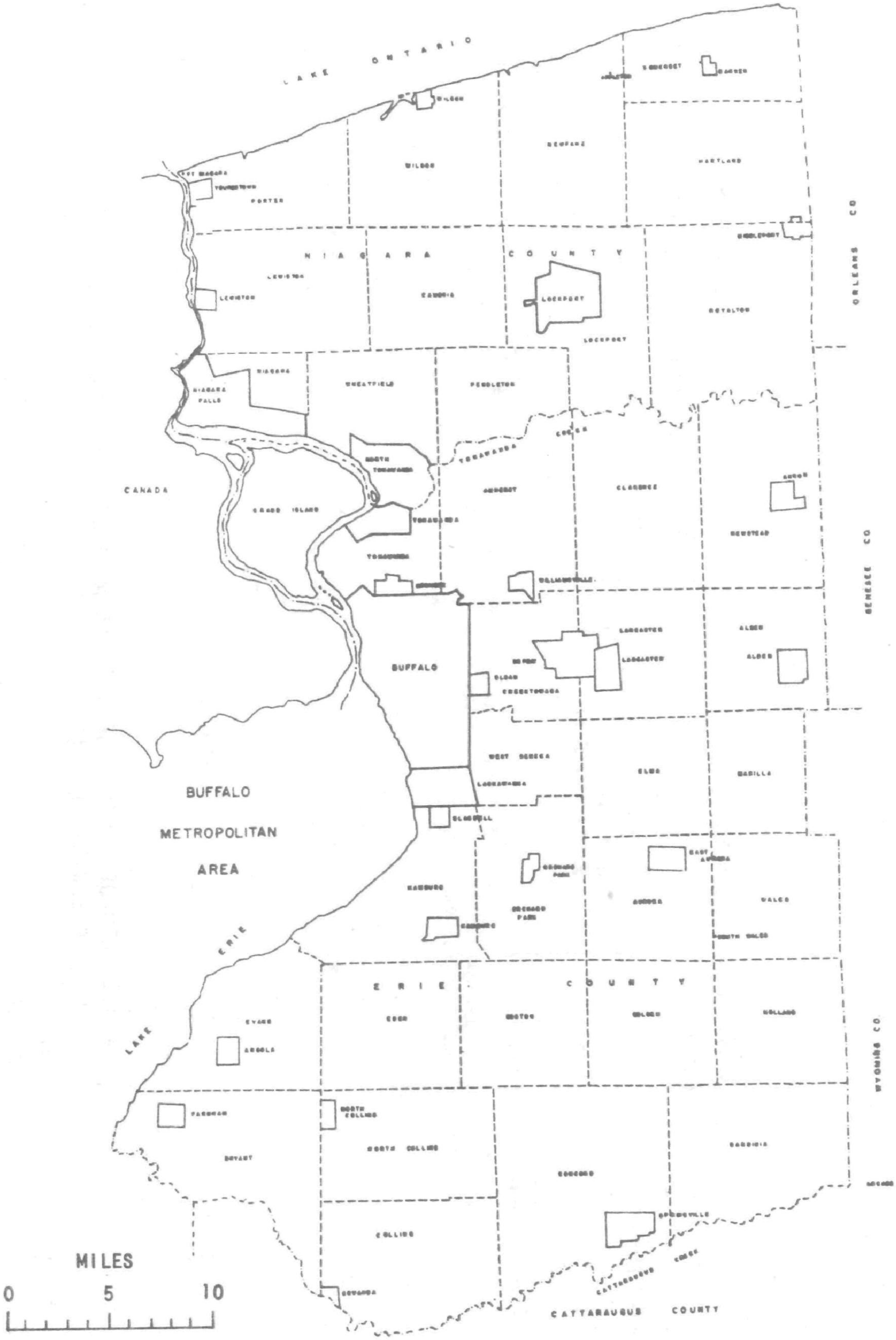

Figure A.1 THE BUFFALO STANDARD METROPOLITAN STATISTICAL AREA

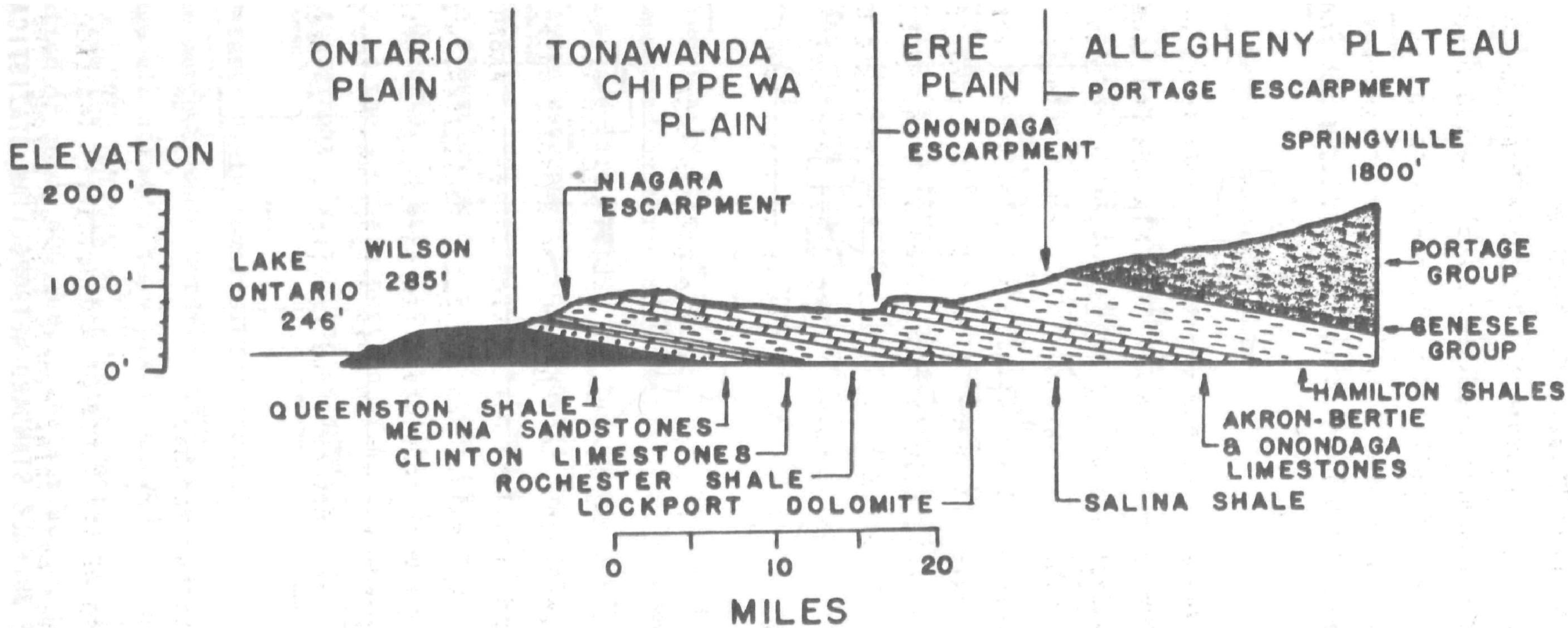

Figure A.2 GEOLOGIC CROSS SECTION FROM WILSON (NIAGARA COUNTY) TO SPRINGVILLE (ERIE COUNTY) level and is cut by the Niagara River. The southern boundary of the Tonawanda-Chippewa Plain is the Onondaga escarpment. The Erie Plain is an essentially level surface south of the Onondaga escarpment and a gentle descent begins in a low region near Lake Erie. Finally, the Allegheny Plateau is located at the southern edge of the Erie Plain and is defined by the range of low hills which reach an elevation of about 2000 feet on hill summits and continues to rise south of Erie County.

The greatest resource of the Great Lakes area is an enormous supply of excellent water. Water shortages in Erie and Niagara Counties are not meaningful; in general under unusual circumstances, they reflect a lack of adequate pumping and distribution systems. The City of Buffalo, using two pumping stations, obtains its water supply from the Niagara River. The Western New York Water Authority pumps its water from Lake Erie. Water obtained from both the Niagara River and Lake Erie is classified as being medium hard, containing 125 parts per million of dissolved inorganic solids. It should be noted that septic tank effluents or sewage disposal plants drain into most of the major streams of Erie and Niagara Counties particularly in their lower courses.

A.2.2. Geographic Highlights of the Buffalo SMSA

The three main factors within the geographic profile which is included here because of their significance to the problems of solid waste are (a) climate and weather, (b) soils and, (c) land utilization patterns. Another factor which is of significance, the major transportation facilities, are not outlined although they have been considered (in particular trafficway networks) in some of the analysis performed within this project and by the planners of solid waste systems (e.g. rail networks and facilities for a potential rail transfer plan).

(a) Climate and Weather

Because of its interior and northerly location in the Nation, the Buffalo region receives many polar fronts passing through the area. Associated with these fronts are variations in weather that occur from day to day and even from hour to hour. Temperatures are decidedly affected by the invasion of fronts, and most of these bring cooler weather, primarily from continental polar air masses descending from Canada. Additionally the temperature regime is considerably affected by the presence of Lake Erie. The summers are several degrees cooler than they would be if no lake influences were present. During winter, Lakes Erie and Ontario contribute considerably milder temperatures to this region then are typical farther inland.

Among some of the other effects on Buffalo's climate and weather which can, in part, be attributed to Lake Erie, are

(1) Increased length of the frost-free season by as much as two-three weeks

(2) Reduced likelihood of smog and smoke over the area because of the higher wind velocities

(3) Increased amount of precipitation

(4) Increased amount of sunshine in summer, as measured by the average percentage of possible sunshine.

In summary, the local influences of Lakes Erie and Ontario, and the somewhat higher areas of the Allegheny Plateau and the Niagara Escarpment do give a somewhat unique character to the climate and weather of the Buffalo SMSA. Such factors as mild winters, cool summers, delayed springs and prolonged falls are a direct result of the Lakes. The heavy snow falls in winter, plus the relatively uniform precipitation regime throughout the year also are partly caused by the control of the Lakes. The relief of the Allegheny Plateau further contributes to the unique character of the local climate by bringing heavy snowfall, and cooler winter and summer temperatures than would be found in more low-lying areas.

(b) Soil

Of the great soil groups that are found in the United States, Erie and Niagara Counties have together three: gray-brown podzolics, bog and half-bog soils, and alluvial soils. With the exception of alluvial or organic soils, the soils of the Erie-Niagara Region have developed from glacial drifts, and associated sands, clays and silts. Some of these soils have developed a layer of tightly packed materials in the subsoil that is slowly permeable to water. Because the pores are small and the horizon or layer holds so little water available to plants, few roots develop in it. Such an impervious layer is known as fragipan and this layer has caused many areas to be rather poorly drained; even some of the moderately sloping areas. A rather high proportion of the New York State drainage problems are a result of the fragipan layer.

A further categorization of the soil groups, known as soil associations, are included on Fig. A.3 and Table A.1 since this categorization is a better indicator of the soil properties which have a direct effect on some solid waste management alternatives; in particular the location of sanitary landfill sites, which would be assessed. Among the soil factors which are of direct interest are the drainage, fertility, structure and bearing capacity characteristics of the soils.

In summary, drainage is the predominant problem with respect to the soil in the Buffalo SMSA. The slowness of drainage limits the uses of the land for residential purposes particularly where individual homes are dependent on septic tanks or drainage fields for the disposal of waste materials.

(c) Land-utilization Patterns

Four rather distinct regions make up the Buffalo SMSA; each of which reflects the evolution or change of land use that has occurred over the years. Both centrifugal and centripetal forces have been at work on the development of the area and are bringing about further changes to both the central city and its surrounding suburbs.

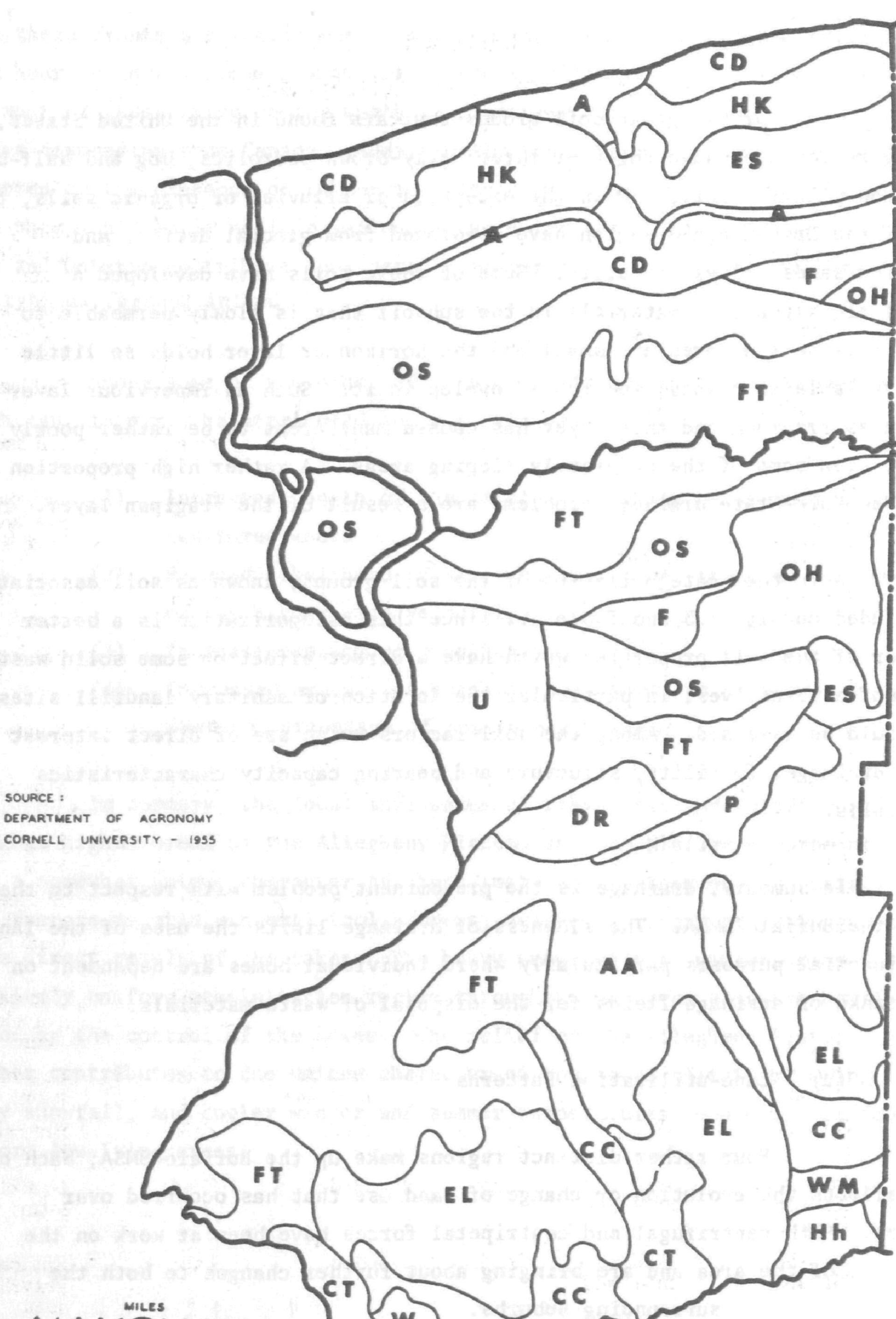

Figure A.3 ERIE-NIAGARA GENERAL SOIL ASSOCIATIONS

Table A.1

KEY TO SOIL ASSOCIATIONS MAP
ERIE-NIAGARA REGION

Map Symbol	Soil Association	Drainage	Fertility	Structure	Bearing Capacity	Composition
A	Alton, Colosse and Ottawa	Poor	Mod. to low	Coarse	Fair	Sandy and gravelly loam
AA	Aurora-Angola	Mod. well to poor	Poor	Med.-fine	Good	Silt loam, silty clay loam
CC	Caneadea-Canadice	Mod. well to poor	Poor	Fine	Good	Silt loam
CD	Collamer-Dunkirk	Well to mod.	Mod.	Med.	Fair	Silt loam
CT	Chenango-Tioga, Howard-Chagrin	Well	High	Good	Good	Silt loam, gravelly loam
DR	Darien-Romulus	Mod. well to poor	Poor	Mod. fine	Good	Silty clay loam
EL	Erie Langford	Mod. well to poor	High to mod.	Med. to med. coarse	Good	Silt loam
ES	Elmwood-Swanton	Mod. well to poor	High	Fine	Poor	Sandy loam
F	Framington and Nollis	Well	High if deep	Med.	Good	Stony loam, silt loam
FT	Fulton-Toledo	Poor to very poor	Fair	Fine	Fair	Silty clay loam
HH	Howard-Hoosic, Chenango, Arkport	Well	Low	Fine	Fair	Silt loam, gravelly loam
HK	Hilton	Mod. well	Mod. to good	Med. fine	Good	Silt loam, gravelly loam
OH	Ontario-Hilton	Well to mod.	High	Med. to mod. fine	Good	Gravelly loam
OS	Odessa-Schoharie	Well to mod. poor	Poor to fair	Med. fine	Fair	Silty clay loam
P	Palmyra, Kars and Herkimer	Well to excessive	High	Med.	Good	Gravelly loam
WM	Wooster-Mardin	Well to mod. well	Mod.	Med.	Fair	Silt loam, gravelly loam
U	Undifferentiated urban lands	—	—	—	—	—

Source: Soils and Soil Association of N.Y., Cornell Extension Bulletin 930 NYS College of Agriculture at Cornell University, Ithaca, N.Y. 1955; and Soil Surveys of Erie and Niagara Counties, N.Y.S. issued 1929 and 1947 respectively. Cornell Agricultural Experiment Station and U.S. Dept. of Agriculture, Bureau of Chemistry and Soils.

The compact urban areas are made up of two subareas which can be designated as blighted (in need of development and rehabilitation), and conservation (in need of general environmental improvement). The blighted subareas generally represent the early settlements in Buffalo, Black Rock, the Tonawandas, Niagara Falls, and Lockport where the age and deterioration of the physical structures and/or environmental deficiencies have combined to produce areas of blight and obsolescence. With few exceptions, the cities of the region are engaged in rehabilitation and revitalization of these core areas of blight. The second subregion can be characterized as having deficiencies in the general environment rather than structural deficiencies. Within this area one finds strip commercial development as well as a scatteration of industrial uses.

The developing suburban areas include such towns as Tonawanda, Amherst, Cheektowaga and West Seneca outside of Buffalo, the towns of Lewiston and Niagara outside of Niagara Falls, and the area of the Town of Lockport south of the City of Lockport. As typical of most metropolitan areas, these areas can be characterized primarily by post-war suburban growth adjacent to the cities. The typical structural development is one-story ranch housing or expandable bungalow, and the shopping plaza.

The suburban fringe areas are typified by scatteration and linear development, and are located between the developing suburban areas and the principal rural areas. This area is more extensive in the northern part of the Buffalo SMSA where level topography, dispersion of major urban centers, and greater amounts of highway network have fostered far-flung dispersion. This regional class is characterized by large open areas which are rapidly being broken up by scattered subdivisions and frontage development along existing highways.

The remainder of the region is predominantly rural farm area including fruit farms, vegetable crops, and dairying. The fruit farms and cropland of the region predominate along the edge of Lake Ontario in Niagara County and on the Erie Plain Lowlands in Erie County where the climate is stabilized by the Lakes. Dairy farming is located mainly in the uplands in the southern part of Erie County. In some areas, the lack of adequate building codes and zoning ordinance has enabled the development of "jerry-built" non-farm residences, improperly planned trailer camps, and a sprinkling of automobile junk yards. These uses are more prevalent on the marginal rural lands in the Tonawanda Creek basin.

A.3 Local Government and Population Distribution Within the Two Counties

A.3.1 Local Government Structure

In attempting to analyze the regional approaches to solid waste management it is of primary importance to be aware of the local governmental structure of the region and the implications of the various forms of government. The political structure of the Buffalo SMSA can be conveniently grouped, in the light of history and function, into three categories: towns and counties; cities and villages; and special purpose units which for the most part are established to render a single service. Erie County consists of three (3) cities, 25 towns, 15 villages, 36 school districts, 884 special districts* for a total of 963 local government units. Niagara County consists of three (3) cities, 12 towns, 5 villages, 10 school districts, 98 special districts* for a total of 128 local government units.

Within New York State, the principal that there should be a substantial amount of local home rule has been long recognized. "Home Rule" refers to the grant of powers to local governmental units and restrictions upon state legislature intervention in local affairs. Local governmental powers gives the citizens of the city or other units of government the power to determine the form and structure of their government. Along with this power, there is the

*Includes the following kinds of districts: Fire, Fire Protection, Street Lighting, Sewer, Drainage, Water, Refuse and Garbage, Park, Consolidated Health and others.

broad power to determine what operating departments shall be established and how the officials responsible for their operations shall be selected. Additionally, the "bill of rights" for local governments which is applicable to all counties, cities, towns and villages grants to each the right to provide services and facilities on a joint or cooperative basis and at the same time to protect its boundaries.

A.3.2 Population Distribution

(a) Erie County

The total population of Erie County, New York, on April 18, 1966 was 1,087,183, according to the final results of a special census taken by the Bureau of the Census, Department of Commerce. This figure represents an increase of 22,495, or 2.1 percent, over the population of April 1, 1960, which was 1,064,688. The population statistics for minor civil divisions and the increases since 1960 are shown in Table A.2. Projections of this County population for the years 1975, 1980 and 2000 were obtained from the Office of the Commissioner of Planning, Erie County. Using this information, estimates of populations were performed on a five-year increment basis up to the year 2000. The total array of population information, by cities and towns within Erie County is presented in Table A.3.

(b) Niagara County

The Bureau of the Census conducted a special census for Niagara County, New York. The special census population as of April 3, 1967 was 234,477. This figure represents a decrease of 7,792 or 3.2 percent, from the 242,269 persons as of April 1, 1960. The population statistics for minor civil divisions (cities, towns and villages) within the County and the changes since 1960 are shown in Table A.4.

Table A.2

POPULATION OF ERIE COUNTY, NEW YORK, BY MINOR CIVIL DIVISIONS: APRIL 18, 1966, AND APRIL 1, 1960

(Minus sign (-) denotes decrease)

Minor civil divisions	April 18, 1966	April 1, 1960	Increase, April 1, 1960, to April 18, 1966	
			Number	Percent
Erie County	1,087,183	1,064,688	22,495	2.1
Alden town	9,445	7,615	1,830	24.0
Alden village	2,694	2,042	652	31.9
Amherst town	79,147	62,837	16,310	26.0
Williamsville village	6,559	6,316	243	3.8
Aurora town	13,970	12,888	1,082	8.4
East Aurora village	6,796	6,791	5	0.1
Boston town	6,273	5,106	1,167	22.9
Brant town	2,532	2,290	242	10.6
Farnham village	480	422	58	13.7
Buffalo city	481,453	532,759	-51,306	-9.6
Cheektowaga town	10,,017	84,056	16,961	20.2
Depew village (pt.)	11,202	7,359	3,843	52.2
Sloan village	5,493	5,803	-310	-5 3
Clarence town	17,001	13,267	3,734	28.1
Colden town	2,624	2,384	240	10.1
Collins town	7,861	6,984	877	12.6
Gowanda village (pt.)	1,050	1,079	-29	-2.7
Concord town	7,162	6,452	710	11.0
Springville village	4,137	3,852	285	7.4
Eden town	7,391	6,630	761	11.5
Elma town	9,113	7,468	1,645	22.0
Evans town	13,110	12,078	1,032	8.5
Angola village	2,550	2,499	51	2.0
Grand Island town	11,294	9,607	1,687	17.6
Hamburg town	44,500	41,288	3,212	7.8
Blasdell village	3,786	3,909	-123	-3.1
Hamburg village	9,493	9,145	348	3.8
Holland town	2,678	2,304	374	16.2
Lackawanna city	28,717	29,564	-847	-2.9
Lancaster town	29,570	25,605	3,965	15.5
Depew village (pt.)	7,107	6,221	886	14.2
Lancaster village	13,408	12,254	1,154	9.4
Marilla town	2,872	2,252	620	27.5
Newstead town	6,151	5,825	326	5.6
Akron village	2,786	2,841	-55	-1.9
North Collins town	4,046	3,805	241	6.3
North Collins village	1,721	1,574	147	9.3
Orchard Park town	17,867	15,876	1,991	12.5
Orchard Park village	3,506	3,278	228	7.0
Sardinia town	2,292	2,145	147	6.9
Tonawanda city	21,946	21,561	385	1.8
Tonawanda town	109,702	105,032	4,670	4.4
Kenmore village	21,146	21,261	-115	-0.5
Wales town	2,640	1,910	730	38.2
West Seneca town	43,397	33,644	9,753	29.0
Cattaraugus Indian Reservation (pt.)	1,400	1,426	-26	-1.8
Tonawanda Indian Reservation	12	30	-18	(B)

B Base less than 100.

Table A.3 PROJECTED POPULATIONS OF CITIES AND TOWNS IN ERIE COUNTY

MINOR CIVIL DIVISION	1970	1975	1980	1985	1990	1995	2000
ALDEN (T)	10500	12000	14000	15800	17300	18400	19000
AMHERST (T)	89000	103000	120000	138000	147000	154000	160000
AURORA (T)	15000	17500	20500	23000	26000	27500	28000
BOSTON (T)	7500	9700	12000	13300	14600	15700	16500
BRANT (T)	3000	3500	4000	4400	4800	5200	5500
BUFFALO (C)	460000	448000	440000	437000	437000	440000	450000
CHEEKTOWAGA (T)	113000	127500	140000	145000	147000	149000	150000
CLARENCE (T)	18500	22000	25000	28000	30500	32500	34000
COLDEN (T)	3000	3900	4500	5000	5400	5700	6000
COLLINS (T)	8500	9300	10500	11900	13300	14500	15400
CONCORD (T)	8000	9100	10500	11700	12800	13700	14500
EDEN (T)	8000	9100	10500	12000	12900	13800	14500
ELMA (T)	10000	12500	15500	17500	19000	20000	21000
EVANS (T)	14000	16000	19000	22000	23500	25000	26000
GRAND ISLAND (T)	12500	15000	18500	21500	23000	24000	25000
HAMBURG (T)	50000	60000	72500	84000	90000	95000	98500
HOLLAND (T)	3000	4100	5000	5700	6200	6700	7000
LACKAWANNA (C)	29000	29700	30500	31300	32000	32500	33000
LANCASTER (T)	33500	40000	48000	53000	59000	63000	65500
MARILLA (T)	3000	3400	4000	4400	4800	5200	5500
NEWSTEAD (T)	7000	8000	9000	9900	10800	11500	12000
NORTH COLLINS (T)	4500	5200	6000	6700	7200	7600	8000
ORCHARD PARK (T)	20500	25000	31000	35000	38000	40000	42000
SARDINIA (T)	2500	2700	3000	3400	3600	3800	4000

Table A.3 PROJECTED POPULATIONS OF CITIES AND TOWNS IN ERIE COUNTY (Cont.)

MINOR CIVIL DIVISION	1970	1975	1980	1985	1990	1995	2000
TONAWANDA (C)	22000	22500	23000	23000	23000	23000	23000
TONAWANDA (T)	112000	116000	120000	120000	120000	120000	120000
WALES (T)	3000	3900	4500	5000	5400	5700	6000
WEST SENECA (T)	48000	60000	78000	84000	87000	89000	90000
CATT. INDIAN RES.	1500	1350	1000	800	650	550	500
ERIE COUNTY	1120000	1199950	1300000	1371500	1421750	1462550	1500400

Table A.4
POPULATION OF NIAGARA COUNTY, NEW YORK, BY MINOR CIVIL DIVISIONS: APRIL 3, 1967, AND APRIL 1, 1960

(Minus sign (-) denotes decrease)

Place	April 3, 1967	April 1, 1960	Increase	
			Number	Percent
Niagara County	234,477	242,269	-7,792	-3.2
Cambria town	4,124	3,661	463	12.6
Hartland town	3,786	3,577	209	5.8
Middleport village (pt.)	142	142	-	-
Lewiston town	15,148	13,686	1,462	10.7
Lewiston village	3,337	3,320	17	0.5
Lockport city	25,616	26,443	-827	-3.1
Lockport town	7,709	6,492	1,217	18.7
Newfane town	9,097	8,523	574	6.7
Niagara town	8,769	7,503	1,266	16.9
Niagara Falls city	88,286	102,394	-14,108	-13.8
North Tonawanda city	35,994	34,757	1,237	3.6
Pendleton town	4,412	3,589	823	22.9
Porter town	6,628	7,309	-681	-9.3
Youngstown village	1,915	1,848	67	3.6
Royalton town	7,034	6,585	449	6.8
Middleport village (pt.)	1,762	1,740	22	1.3
Somerset town	2,453	2,489	-36	-1.4
Barker village	553	528	25	4.7
Wheatfield town	9,356	8,008	1,348	16.8
Wilson town	4,962	5,319	-357	-6.7
Wilson village	1,271	1,320	49	3.7
Tonawanda Indian Reservation (pt.)	-	-	-	-
Tuscarora Indian Reservation	1,103	1,934	-831	-43.0

- Represents zero.

A.3.3 Economic Profile of the Erie-Niagara Area

A brief economic profile of the Buffalo SMSA is included in this Appendix because of the contributions that the various economic sectors provide to the regional waste streams. Although no single economic indicator, e.g. number of employees, income generated, productivity, etc., is currently available for relating the impact of economic activity on solid waste, a study is being performed at the University of California (Ref. 15) to develop an economic input-output matrix and to derive relationships between this matrix and regional solid waste generation by individual economic sectors. The development of the matrix and its relationships with solid waste generation would be an invaluable tool for making projections of the types and quantities of solid waste to be handled, and for assessing alternative systems and their capabilities for handling various quantities and types of industrial and commercial waste.

As a single measure, employment within individual employment categories can be a useful proxy in indicating changing levels of economic activity within the category. Assuming that the relationship between number of employees and solid waste generated within the employment category can be measured, it should be fairly routine to estimate changes in solid waste for changing employment levels. Caution in making these estimates must be exercised since these relationships are dependent on materials, methods and other technological changes which can affect the types and quantities of waste generated per unit of labor input.

The economic description of the Buffalo SMSA is described, in part, in terms of employment because of the seeming relationship between industrial and commercially-generated solid waste and given employment levels. A regional economic discussion is useful because of the relationship between employment opportunities, or the lack thereof, and migratory patterns. The level of migration resulting from changes in the region's economic activity plays an obvious role in the levels of residential solid waste generated.

A summary of the 1966 Erie-Niagara employment breakdown by broad employment categories is presented in Table A.5.

Table A.5 ERIE-NIAGARA EMPLOYMENT CATEGORIES 1966

(Nonagricultural Establishments)

Category	Total Percent of Employment
Manufacturing	38.6%
Trade	19.2
Government	14.2
Services	13.3
Transportation & Private Utilities	6.7
Contract Construction	4.2
Finance, Insurance, Real Estate	3.7

It is apparent that manufacturing provides the largest percentage of jobs in the Buffalo SMSA, and in comparison with the Nation it is substantially larger (38.6% vs. 29.8%). Along with this static representation of the employment for a given year (1966), it is useful for projective purposes to examine the rates of change which have been experienced. The form of the information, presented in Table A.6, Erie-Niagara Area Employment, for the years 1958 and 1966 depicts levels of employment in each of the categories shown in Table A.5 although the percent changes are in terms of absolute employment levels in each sector rather than among the employment categories, as a percent of total employment.

Based on the past and present employment data as well as an assessment of the Area's economic strengths and weaknesses vis a vis the Nation, it is anticipated that employment opportunities in the Buffalo SMSA are expected to increase by about half by the year 2000. This increase compares with an anticipated doubling for the Nation. The industrial employment mix in the area will shift dramatically with the proportion of the working population in manufacturing declining from roughly two-fifths in 1950 to less than one-third in 2000.

Manufacturing employment will probably increase by about one-quarter by the year 2000, as increased production requirements will be met largely by improved technology rather than by proportionate increases in manpower. Most

Table A.6

Erie-Niagara Area Employment

1958-1966

Industry	*1958*	*1966*	*Percent Change*
Total Nonagricultural Employment	432,300	472,800	+ 9.4
Manufacturing	175,500	180,500	+ 2.8
Durable Goods	114,900	123,300	+ 7.3
Abrasive Cement & Plastic Products	8,500	8,200	— 3.5
Primary Metals Industry	31,200	33,600	+ 7.7
Fabricated Metals Including Ordnance	14,300	14,100	— 1.4
Machinery Except Electrical	13,100	15,000	+14.5
Electrical Machinery, Equipment, Supplies	11,800	15,000	+27.1
Transportation Equipment	30,600	31,400	+ 2.6
Nondurable Goods	60,600	57,200	— 5.6
Food & Kindred Products	16,400	14,100	—14.0
Apparel & Textile Mill Products	4,200	3,600	—14.3
Paper & Allied Products	7,200	7,000	— 2.8
Printing & Publishing	7,600	8,400	+10.5
Chemicals & Allied Products	17,500	16,000	— 8.6
Rubber & Miscellaneous Plastic Products	4,000	4,700	+17.5
Nonmanufacturing	256,800	292,200	+13.8
Contract Construction	22,500	20,200	—10.2
Transportation & Public Utilities	34,300	31,900	— 7.0
Wholesale & Retail Trade	86,600	91,900	+ 6.1
Finance, Insurance & Real Estate	15,500	16,900	+ 9.0
Service & Miscellaneous	51,400	64,400	+25.3
Government	46,400	67,000	+44.4

SOURCE: NYS Department of Labor, Division of Employment.

of the expansion in jobs will be concentrated in the growing machinery and transportation equipment industries. Gains on the already well developed primary metals lines will be relatively moderate. Nondurable goods gains will be limited, with absolute declines expected in textiles and apparel. The chemicals industry will be characterized by rapid technological changes and geographic shifts and can only anticipate modest personnel gains by 2000. This projection assumes a reversal in the downtrend of recent years.

Nonmanufacturing jobs in the Buffalo SMSA are expected to double by 2000. All nonfactory lines except the extractive lines in the metropolitan area should show substantial employment gains as the shift from a producing to a servicing job market continues. Greatest advances are most likely to occur in fields such as personal and business services, amusement and recreation, medical services and education. Retail and wholesale gains will be second only to that of the services and will reflect proliferation of demands for the amenities by an increasingly affluent society.

The emphasis on manufacturing tends to obscure the gaining importance of education, medical and scientific research, government and nonindustrial fields. The great metalworking - machinery - auto and chemical complex that has been the manufacturing strength of the Buffalo SMSA economy will continue to play a leading role. Table A.7 depicts the relative gains in nonmanufacturing jobs in the years ahead and indicates that these employment categories will greatly exceed those for manufacturing categories by the year 2000.

Table A.7

Erie-Niagara Area Employment Projections — Major Industry Groups

1960-2000

Manufacturing	*1960*	*1980*	*2000*
Manufacturing	181,166	199,000	218,500
Food & Food Products	16,039	16,700	17,400
Textiles	1,376	1,200	1,000
Apparel	2,600	2,400	2,200
Furniture & Wood Products	4,096	4,100	4,100
Printing & Publishing	10,417	12,000	13,900
Chemicals	17,660	18,800	20,000
Primary Metals & Fabricated Products	46,197	49,000	51,800
Machinery	26,863	33,600	41,300
Transportation Equipment	30,597	35,000	40,000
Nonmanufacturing	289,695	395,000	540,900
Construction	27,388	27,800	36,800
Transportation, Communication and Public Utilities	35,915	44,800	53,300
Wholesale and Retail Trade	85,047	121,600	169,300
Finance, Insurance & Real Estate	16,849	22,900	30,200
Services	87,644	133,800	198,000
Public Administration	18,553	25,800	34,900
Agriculture, Forestry & Fisheries	5,575	4,600	3,900

SOURCE: U. S. Census Bureau, N. Y. S. Division of Water Resources, and GBDF.

APPENDIX B: BUFFALO SMSA SOLID WASTE GENERATION

B.1 Introduction

Included in Appendix B are descriptions of the broad categories of solid waste; the various alternatives for depicting the solid waste of a region as it related to specific objectives; estimates of current solid waste generated; and finally projections of solid waste generated to the year 2000. Although the term generation is employed, it is recognized that it is some combination of generation and collection. For example in those rural residential areas where sufficient land is available, some of the solid waste is disposed of on-site and may not be accounted for in the regional totals. Also, in those areas where home food grinders are found, a significant amount of garbage enters the liquid waste stream and is not accounted for in the regional solid waste generation category. Additional sources of error in estimating the regional solid waste generated result from on-site open burning and home incinerator practices. Each of these practices are beneficial from the standpoint that the load on the regional solid waste system is reduced, to varying degrees. However unless the magnitude of solid waste disposed of by these methods can be assessed, the consequences on any regional solid waste handling system of terminating these practices would be very difficult to assess.

As a result of discussions with responsible City and County officials, and representatives of the private sector of the solid waste industry, it has been found that there doesn't exist a comprehensive and accurate estimate of solid waste generated in the Buffalo SMSA. A review of many reports and documents, as well as discussions with representatives of the Solid Wastes Program, reveals that this lack of comprehensive and accurate information is wide-spread. To correct this important deficiency,major fundings and efforts are being supported to obtain more complete and accurate information so as to better understand the scope of the solid waste handling problems and to allow for better planning.

In spite of these shortcomings it is both possible and necessary to perform the requisite planning although caution must be exercised in accepting and utilizing the extant data. To overcome the limitations of this data and projections derived therefrom, it is necessary to introduce a variety of logical and consistent assumptions concerning solid waste generation and to establish the sensitivity of the solid waste handling solutions to variations in the assumptions and the derived projections.

B.2 Description of Solid Waste

Although some of the contents of this portion of the Appendix are contained within other documents and in some instances are either direct quotes or paraphrases of published material, the information is included for its relevance to the latter portions of the Appendix and for greater completeness of the discussion. Whereas the description of solid waste should be given more extensive treatments, the following description is indicative of the types of information and data required to aid solid waste managers.

B.2.1 Categories of Solid Waste

In the main, solid waste and refuse are synonomous terms. The constituents of solid waste may be classified in numerous ways. One of the more useful classification schemes, as described in Ref. 4, is based on the kinds of materials which constitute solid waste: garbage, rubbish, ashes, street refuse, dead animals, abandoned automobiles, industrial wastes, demolition wastes, construction wastes, sewage treatment residues and special wastes. Table B.1 groups refuse materials by kind, composition, percent combustible volume, percent noncombustible volume, and some of the major sources of the refuse.

Table B.1

SOLID WASTE MATERIALS BY KIND, COMPOSITION, COMBUSTIBLE VOLUME, AND SOURCES

KIND		COMPOSITION	COMBUSTIBLE VOLUME (%)	NONCOMBUSTIBLE VOLUME (%)	SOURCES
Refuse	Garbage	Wastes from preparation, cooking, and serving of food; market wastes; wastes from handling, storage, and sale of produce	90-100	0-10	Households, restaurants, institutions, stores, markets
	Rubbish	Combustible: paper, cartons, boxes, barrels, wood, excelsior, tree branches, yard trimmings, wood furniture, bedding dunnage	70-85	15-30	
		Noncombustible: metals, tin cans, metal furniture, dirt, glass, crockery, minerals	0	100	
	Ashes	Residue from fires used for cooking and heating and from on-site incineration	0	100	
	Street Refuse	Sweepings, dirt, leaves, catch basin dirt, contents of litter receptacles	30-70	30-70	Streets, sidewalks, alleys, vacant lots
	Dead Animals	Cats, dogs, horses, cows	95	5	
	Abandoned Vehicles	Unwanted cars and trucks left on public property	0-10	90-100	
	Industrial Wastes	Food processing wastes, boiler house cinders, lumber scraps, shavings	40-90	10-60	Factories, power plants
	Demolition Wastes	Lumber, pipes, brick, masonry, and other construction materials from razed buildings and other structures	5-25	75-95	Demolition sites to be used for new buildings, renewal projects, expressways
	Construction Wastes	Scrap lumber, pipe, other construction materials	5-25	75-95	New construction, remodeling
	Special Wastes	Hazardous solids and liquids: explosives, pathological wastes, radioactive materials	80-95	5-20	Households, hotels, hospitals, institutions, stores, industry
	Sewage Treatment Residue	Solids from coarse screening and from grit chambers; septic tank sludge	75-90	10-25	Sewage treatment plants; septic tanks

B.2.2 Categorization of Solid Waste - For What Purpose?

As the formulation of evaluation structures and mathematical models in systems analysis is predicted on a specific question or questions being examined so should the development of a typology or categorization scheme for solid waste be responsive to the uses to which the information would be applied. Within Section B.1 it was stated that there is a lack of information on a comprehensive and well-established basis of solid waste generation in the Buffalo SMSA as well as most other regions in the United States. What is implied by this statement is that the information currently available meets certain limited needs but is either lacking or inadequate for many other needs for efficient solid waste management. The evidence of these data deficiencies is best appreciated when examining the approaches taken by most studies of the problems of solid waste management. Almost universally, one of the first steps taken is to design a survey, collect and collate solid waste information. Based on the time, funds and effort available, this activity is pursued in varying degrees of detail and completeness. Since most of these studies are of the broad planning variety, the types of data being collected and analyzed are related to the more general aspects of the planning function.

Among the major purposes to which solid waste information is applied are (1) operations; (2) planning and; (3) research. Each of these purposes has information requirements which can be grossly described as common and unique. As examples of common information are such elements as the types and the projection of changes in types and amounts of solid waste generated. With respect to unique information needs, the operations function is concerned with the work loads of specific and individual crews and pieces of equipment, current maintenance problems and schedules, manpower recruitment and training status -- virtually all of this information pertains to the here and now. The planning function is in need of information which allows for the consideration of the types of major system modifications which would improve the "system operation" both on a near-term and long-term basis. These improvements and the types of information required are restricted to those decisions and implementations which can be directly influenced by the solid waste planners. As vital portions of these information requirements are

(i) long-range projections (up to 25 years or more) of types and quantities of solid waste which would be generated; (ii) anticipations and assessments of changes in the attitudes of the population with respect to solid waste handling practices, (iii) pending or foreseeable legislation which influences and/or limits solid waste decisions; and (iv) technological innovations. The unique information needs of the research function are difficult to describe since they are highly dependent on problems which either are in the definitional phase or have not been defined. It can be stated that whereas the operator's needs are closely related to the present, the planners needs relate to those problems which they can directly influence, and the researcher's needs are not bounded. As examples of the researcher's information needs are the properties (chemical, physical) of refuse constituents as they relate to a specific research waste handling technique (e.g. high temperature incineration) being studied; and the incidence of illness and fatality as related to various air pollution constituents which are traceable to solid various waste handling practices.

No attempt has been made in this study to set up a categorization scheme for meeting the information requirements of these different interests. However, emphasizing this deficiency, which is currently but all too slowly being recognized, is of value and in particular noting the need for recognizing the unique information requirements of the three major functions. The development and operation of regional solid waste data banks which are responsive to the operators and planners is technically feasible with the advent of electronic data processing and it could also meet certain needs of researchers. A significant effort in this direction is being undertaken by the Los Angeles Bureau of Sanitation [Ref. 21]. Although the main orientation of this information system is to meet the needs of the operation function, it is an indication of what could be done for the planners and to some degree, the researchers.

B.2.3 State of Solid Waste Information Pertaining to the Buffalo SMSA

Within the past two years, two broad planning studies were performed of refuse disposal for the Buffalo SMSA; a 1966 study of Niagara County and a 1967 study of Erie County (Refs. 22 and 24). Both investigations, of rather modest effort, were confronted with the problem of obtaining current solid waste handling information which was required to assist in establishing the processing and disposal facility requirements out to the year 2000. Through the use of sampling surveys, data of varying quality and completeness were obtained. Using this information with various assumptions and national planning coefficients, a variety of material flow and cost analyses was performed and recommendations for new processing and disposal facilities over the time period of interest were made. Within the limitations confronting the consultants, it appears that they provided useful planning directions but it is evident that the foundations of their planning recommendations, as well as those derived by most consultants are highly dependent on the solid waste information available and the assumptions made. An examination of the studies did not indicate any sensitivity analyses of the recommendations relative to the assumptions employed or the estimates made.

Among the many factors which present difficulties in obtaining a reliable estimate of the solid waste generated and handled in the Buffalo SMSA are:

(1) A lack of uniformity in the types and details of the information collected by the political subdivisions within the region providing refuse collection and disposal functions.

(2) Little and imprecise information is maintained by private collectors and private disposal operators as to the sources, types and quantities of refuse handled.

(3) No up-to-date inventories are maintained of on-site disposal facilities in terms of available capacities or their expected operating lives.

(4) No information is maintained which indicates the types and amount of refuse processed or disposed of on-site by residential sources and other sources.

(5) Where information is collected and maintained by private collectors, it is difficult to obtain these data because of the competitive nature of the industry and their fears of improper disclosure.

(6) The lack of an operative measurement equipment at certain incinerators and disposal sites.

The above factors, by and large, are quite similar for most other regions. Yet in spite of these limitations it is possible to develop a gross picture of the solid waste handling in the Buffalo SMSA which is being used for operational and planning purposes.

B.3 Spatial Distribution of Solid Waste Generated.

The current manner of depicting the spatial distribution of solid waste generated in the Buffalo SMSA is a conglomerate of collection districts, civil boundaries and specific locations. The establishment and stability of collection districts are largely dependent on work load considerations and on some equitable sharing of the total collection burden. Thus the size and number of districts are influenced by such factors as population shifts, urban renewal, equipment capacity, etc. Civil boundaries with respect to solid waste collection are used for the administrative and taxing conveniences and have little or no relationship to the effective management of solid waste. In some special situations, specific locations are used to depict the location of solid waste generation; where the type and/or quantity of solid waste is either unique or very large.

After reviewing a number of different methods of describing the spatial distribution of solid waste generation, it was decided to employ the census tracts, as defined by the Bureau of Census, U.S. Department of Commerce. For the examination of collection, transportation and facility siting problems, it appeared that the towns and cities represent too large an area to employ for analysis. The advantages of employing a census tract system for analyzing solid waste problems are as follows:

(1) The boundaries are fairly stable. Although some alternations have been made to the boundaries over the years, the changes have been in the form of subdivisions of the original boundaries with the new designations being related to the original ones;

(2) The secondary source data (e.g. population, land-use, income, households etc.) which is useful for estimating current per capita solid waste generation and for projecting residential generation is gathered and operated on a census tract basis;

(3) Census tract areas are sufficiently small so as to allow for the use of a "pseudo-point" source for tract solid waste generation in the analysis of transportation of solid waste to processing plants and/or disposal sites;

(4) Census tracts are contained entirely within major political subdivisions and thus, by appropriate aggregation, the waste generation of an entire political subdivision can be derived;

(5) Finally, greater socio-economic homogeneity is found within a single census tract than exists within the larger political subdivisions.

1.4 Estimate of Current Solid Waste Generation in Erie County

Although the term generation has been used primarily throughout this Appendix it is more accurate to describe the following information as an estimate of solid waste collected. Virtually all of the available data sources which have been examined refer to the solid waste collected by public and private solid waste operators. Two exceptions to this have been the partial surveys made within the aforementioned Erie and Niagara County Studies. Within the Erie County Study a sample survey was conducted by mailed questionnaires of certain service and industrial organizations and a rather gross adjustment was made to account for the non-respondents to the questionnaire. No over-all estimates were included of on-site incineration or grinders. With respect to the Niagara County Study, a survey was made which was restricted to the large industrial firms with no estimate of on-site disposal practices being shown.

An estimation of the current solid waste "collected" by census tracts was made for the City of Buffalo,* and the remainder of Erie County. Since the data available for the City of Buffalo are in terms of the collection districts, the data was subsequently translated into the census tract basis being utilized within this study. This translation was predicated primarily on a uniform population distribution being assumed for the individual collection districts except for those instances where the land-use patterns (e.g. parks, industrial areas, shopping centers, institutions, etc.) indicated otherwise. Although the City of Buffalo collection included some nonresidential refuse (light commercial), no data are available to estimate the proportions of refuse which is obtained from residences and the proportions from the other sources. The estimation procedure for the remainder of Erie County entailed the assignment of the total amount of refuse (exclusive of that which is clearly identified as generated by commerce and industry) to the census tracts in direct proportion to the populations residing within each tract.

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*The data utilized was provided by the Office of the Commissioner of Streets and Sanitation, City of Buffalo.

The results of these estimating procedures are shown in Tables B.2 and B.3 (City of Buffalo), Tables B.4 and B.5 (Remainder of Erie County), and Figs. B.1 and B.2

B.5 Future Solid Waste Generation

As described in Waste Management (Ref. 1), estimating future solid waste is difficult because of the many variables influencing the estimate. The two most significant factors affecting the magnitude and characteristics of generated solid waste have been the significant changes in packaging practices and in fuel selection. The impact of packaging practices, which has resulted in a sizable increase in the amount of paper and paper products as well as the proportion of these materials constituting refuse, has resulted in a decrease in food wastes. Additionally, plastics associated with packaging is being encountered and it can be expected that the quantity will increase significantly over the 35 year projection period. Noncombustible solid waste have increased as a result of industry decisions concerning nonreturnability of containers and the expanded uses of cans. With respect to fuels used for household heating and industrial applications, there is a continuous diminution in ashes, in particular within household heating, and it can be expected that the increased uses of gas, oil and nuclear fuels will result in the virtual disappearance of ashes by the end of the 35-year planning period.

With these major changes as well as others being brought about by technological and economic factors the composition (type of materials and their proportions) of refuse will be affected and thus influence the processing and disposal decisions. For example, aluminum and plastics are virtually nondegradable. Aluminum may be incinerated at high temperatures, but this results in gaseous wastes which could lower air quality. A similar affect is experienced from the incineration of plastics. Glass when introduced into a normal temperature incincerator will melt but seldom burn and is nondegradable in landfills. It has been found that the degradability of plastic-lined paper containers is very low.

Table B.2

ESTIMATED REFUSE QUANTITIES FOR CENSUS TRACTS WITHIN CITY OF BUFFALO, 1966 (TONS PER DAY)

CENSUS TRACT	COORDINATES	PRIVATE COLLECTION TOTAL	PRIVATE COLLECTION NON-COMBUSTIBLE	PRIVATE COLLECTION COMBUSTIBLE	MUNICIPAL COMBUSTIBLE	TOTAL COMBUSTIBLE	TOTAL REFUSE
1	5.95, 2.50	26.96	26.96	--	5.84	5.84	32.80
2	6.34, 3.60	63.54	63.54	--	12.10	12.10	75.64
3	5.30, 3.49	22.23	22.23	--	2.45	2.45	24.68
4	5.90, 4.52	31.62	15.81	15.81	1.54	17.35	33.16
5	4.59, 4.30	--	--	--	6.06	6.06	6.06
6	6.88, 2.50	--	--	--	13.25	13.25	13.25
7	7.50, 2.50	--	--	--	9.01	9.01	9.01
8	6.91, 3.17	--	--	--	12.85	12.85	12.85
9	7.00, 3.62	--	--	--	5.94	5.94	5.94
10	7.59, 3.60	5.46	2.73	2.73	14.83	17.56	20.29
11	7.00, 4.30	--	--	--	7.55	7.55	7.55
12	4.90, 5.20	18.38	9.19	9.19	9.17	18.36	27.55
13	3.90, 5.10	43.31	32.48	10.83	6.80	17.63	50.11
14	4.44, 5.96	10.85	2.71	8.14	26.86	35.00	37.71
15	5.12, 6.00	--	--	--	14.10	14.10	14.10
16	5.95, 6.30	8.35	2.09	6.26	19.82	26.08	28.17
17	5.89, 5.73	7.08	3.54	3.54	6.95	10.49	14.03
18	5.72, 5.15	5.31	2.66	2.65	2.81	5.46	8.12
19	7.39, 4.75	--	--	--	7.92	7.92	7.92
20	6.55, 5.39	14.15	10.61	3.54	10.55	14.09	24.70
21	7.25, 5.55	--	--	--	2.09	2.09	2.09
22	7.65, 5.30	--	--	--	4.56	4.56	4.56
23	7.15, 6.14	--	--	--	8.57	8.57	8.57
24	7.20, 6.60	2.88	0.72	2.16	15.04	17.20	17.92
25	4.30, 6.45	75.23	37.62	37.61	41.12	78.73	116.35
26	5.05, 6.65	--	--	--	6.38	6.38	6.38
27	5.74, 6.95	4.65	2.33	2.32	26.98	29.30	31.63
28	6.71, 7.10	4.31	2.16	2.15	14.99	17.14	19.30
29	6.80, 7.60	--	--	--	11.09	11.09	11.09
30	7.60, 7.50	--	--	--	6.50	6.50	6.50
31	4.63, 7.10	5.31	2.12	3.19	20.49	23.68	25.80
32	4.55, 7.92	7.65	3.06	4.59	26.66	31.25	34.31
33	5.15, 8.05	4.31	1.08	3.23	26.30	29.53	30.61
34	6.00, 8.40	76.27	68.64	7.63	11.90	19.53	88.17
35	5.99, 7.74	33.35	26.68	6.67	16.65	23.32	50.00
36	6.83, 8.25	1.35	0.34	1.01	11.71	12.72	13.06

Table B.2 (Cont.)

ESTIMATED REFUSE QUANTITIES FOR CENSUS TRACTS WITHIN CITY OF BUFFALO, 1966 (TONS PER DAY)

CENSUS TRACT	COORDINATES	PRIVATE COLLECTION TOTAL	PRIVATE COLLECTION NON-COMBUSTIBLE	PRIVATE COLLECTION COMBUSTIBLE	MUNICIPAL COMBUSTIBLE	TOTAL COMBUSTIBLE	TOTAL REFUSE
37	7.40, 8.25	--	--	--	11.16	11.16	11.16
38	7.80, 8.29	--	--	--	6.51	6.51	6.51
39	6.42, 9.15	23.19	9.28	13.91	10.08	23.99	33.27
40	5.85, 9.49	12.81	3.20	9.61	16.22	25.83	29.03
41	7.49, 9.00	--	--	--	12.04	12.04	12.04
42	6.90, 9.70	22.73	11.37	11.36	7.71	19.07	30.44
43	7.50, 10.40	--	--	--	12.33	12.33	12.33
44	7.59, 9.71	--	--	--	13.77	13.77	13.77
45	5.83, 10.55	3.31	0.85	2.46	13.68	16.14	16.99
46	6.78, 11.14	--	--	--	12.28	12.28	12.28
47	6.70, 10.45	--	--	--	12.04	12.04	12.04
48	5.15, 10.66	--	--	--	8.69	8.69	8.69
49	4.59, 10.71	--	--	--	9.98	9.98	9.98
50	3.80, 10.80	28.50	22.80	5.70	5.70	11.40	34.20
51	4.63, 11.24	--	--	--	10.40	10.40	10.40
52	5.35, 9.35	--	--	--	15.06	15.06	15.06
53	4.65, 9.50	--	--	--	1.72	1.72	1.72
54	4.14, 9.99	36.50	29.20	7.30	8.00	15.30	44.50
55	2.90, 10.04	39.08	31.26	7.82	9.50	17.32	48.58
56	3.10, 10.84	23.69	17.77	5.92	9.99	15.91	33.68
57	2.40, 10.74	9.35	7.01	2.34	7.77	10.11	17.12
58	2.22, 11.30	--	--	--	20.10	20.10	20.10
59	2.15, 9.95	--	--	--	9.78	9.78	9.78
60	2.70, 9.01	10.04	7.53	2.51	10.50	13.01	20.54
61	2.50, 8.31	1.85	0.46	1.39	9.98	11.37	11.83
62	3.25, 9.40	--	--	--	11.20	11.20	11.20
63A	3.30, 8.80	--	--	--	10.86	10.86	10.86
63B	3.81, 8.96	--	--	--	8.12	8.12	8.12
64	4.30, 8.84	--	--	--	1.93	1.93	1.93
65A	3.25, 8.32	--	--	--	5.54	5.54	5.54
65B	3.99, 8.35	--	--	--	7.53	7.53	7.53
66A	3.29, 8.01	--	--	--	7.12	7.12	7.12
66B	3.90, 8.01	--	--	--	4.82	4.82	4.82
67	3.64, 7.59	--	--	--	14.76	14.76	14.76
68	3.60, 6.99	14.42	3.61	10.81	12.26	23.07	26.68
69	2.90, 7.60	--	--	--	23.28	23.28	23.28
70	2.50, 7.26	--	--	--	11.77	11.77	11.77
71	2.95, 6.50	2.88	1.44	1.44	25.35	26.79	28.23
72	3.45, 5.95	6.42	3.21	3.21	2.82	6.03	9.24
	TOTALS	707.32	488.29	219.03	859.78	1078.81	1567.10

Table B.3

ESTIMATED REFUSE QUANTITIES PER SQUARE MILE FOR CENSUS TRACTS WITHIN CITY OF BUFFALO 1966 (TONS PER DAY PER SQUARE MILE)

CENSUS TRACT	COORDINATES	AREA (SQ.MI.)	MUNICIPAL COMBUSTIBLE	TOTAL COMBUSTIBLE	TOTAL REFUSE
1	5.95, 2.50	1.61	3.62	3.62	20.37
2	6.34, 3.60	0.50	24.20	24.20	151.28
3	5.30, 3.49	2.18	1.12	1.12	11.32
4	5.90, 4.52	0.56	2.75	30.98	59.21
5	4.59, 4.30	1.37	4.42	4.42	4.42
6	6.88, 2.50	0.45	29.44	29.44	29.44
7	7.50, 2.50	0.42	21.45	21.45	21.45
8	6.91, 3.17	0.43	29.88	29.88	29.88
9	7.00, 3.62	0.22	27.00	27.00	27.00
10	7.59, 3.60	0.83	17.86	21.15	24.44
11	7.00, 4.30	0.59	12.79	12.79	12.79
12	4.90, 5.20	0.69	13.28	26.60	39.92
13	3.90, 5.10	1.10	6.18	16.02	45.55
14	4.44, 5.96	0.50	53.72	70.00	75.42
15	5.12, 6.00	0.41	34.39	34.39	34.39
16	5.95, 6.30	0.57	34.77	45.75	49.42
17	5.89, 5.73	0.49	14.18	21.40	28.63
18	5.72, 5.15	0.35	8.02	15.60	23.20
19	7.39, 4.75	0.49	16.16	16.16	16.16
20	6.55, 5.39	0.78	13.52	18.06	31.66
21	7.25, 5.55	0.46	4.54	4.54	4.54
22	7.65, 5.30	0.28	16.28	16.28	16.28
23	7.15, 6.14	0.49	17.48	17.48	17.48
24	7.20, 6.60	0.75	20.05	22.93	23.89
25	4.30, 6.45	0.60	68.53	131.21	193.91
26	5.05, 6.65	0.18	35.44	35.44	35.44
27	5.74, 6.95	0.67	40.26	43.73	47.20
28	6.71, 7.10	0.52	28.82	32.96	37.11
29	6.80, 7.60	0.33	33.60	33.60	33.60
30	7.60, 7.50	0.51	12.74	12.74	12.74
31	4.63, 7.10	0.60	34.15	39.46	43.00
32	4.55, 7.92	0.68	39.20	45.95	50.45
33	5.15, 8.05	0.69	38.11	42.79	44.36
34	6.00, 8.40	0.59	20.16	33.10	149.44
35	5.99, 7.74	0.62	26.85	37.61	80.64
36	6.83, 8.25	0.51	22.96	24.94	25.60

Table B.3 (Cont.)

ESTIMATED REFUSE QUANTITIES PER SQUARE MILE FOR CENSUS TRACTS WITHIN CITY OF BUFFALO 1966 (TONS PER DAY PER SQUARE MILE)

CENSUS TRACT	COORDINATES	AREA (SQ.MI.)	MUNICIPAL COMBUSTIBLE	TOTAL COMBUSTIBLE	TOTAL REFUSE
37	7.40, 8.25	0.46	24.26	24.26	24.26
38	7.80, 8.29	0.24	27.12	27.12	27.12
39	6.42, 9.15	0.63	16.00	38.07	52.80
40	5.85, 9.49	0.77	21.06	33.54	37.70
41	7.49, 9.00	0.51	23.60	23.60	23.60
42	6.90, 9.70	0.40	19.27	47.67	76.10
43	7.50,10.40	0.47	26.23	26.23	26.23
44	7.59, 9.71	0.59	23.33	23.33	23.33
45	5.83,10.55	0.78	17.53	20.69	21.78
46	6.78,11.14	0.80	15.35	15.35	15.35
47	6.70,10.45	0.62	19.41	19.41	19.41
48	5.15,10.66	0.40	21.72	21.72	21.72
49	4.59,10.71	0.45	22.17	22.17	22.17
50	3.80,10.80	0.51	11.17	22.35	67.05
51	4.63,11.24	0.45	23.11	23.11	23.11
52	5.35, 9.35	0.67	22.47	22.47	22.47
53	4.65, 9.50	0.80	2.15	2.15	2.15
54	4.14, 9.99	0.77	10.38	19.87	57.79
55	2.90,10.04	0.59	16.10	29.35	82.33
56	3.10,10.84	0.82	12.18	19.40	41.07
57	2.40,10.74	0.36	21.58	28.08	47.55
58	2.22,11.30	0.66	30.45	30.45	30.45
59	2.15, 9.95	0.49	19.95	19.95	19.95
60	2.70, 9.01	0.74	14.18	17.58	27.75
61	2.50, 8.31	0.47	21.23	24.19	25.17
62	3.25, 9.40	0.38	29.47	29.47	29.47
63A	3.30, 8.80	0.24	45.25	45.25	45.25
63B	3.81, 8.96	0.39	20.82	20.82	20.82
64	4.30, 8.84	0.24	8.04	8.04	8.04
65A	3.25, 8.32	0.19	29.15	29.15	29.15
65B	3.99, 8.35	0.28	26.89	26.89	26.89
66A	3.29, 8.01	0.15	47.46	47.46	47.46
66B	3.90, 8.01	0.16	30.12	30.12	30.12
67	3.64, 7.59	0.54	27.33	27.33	27.33
68	3.60, 6.99	0.35	35.02	65.91	76.22
69	2.90, 7.60	0.49	47.51	47.51	47.51
70	2.50, 7.26	0.56	21.01	21.01	21.01
71	2.95, 6.50	0.66	38.40	40.59	42.77
72	3.45, 5.95	0.57	4.94	10.57	16.21
AVERAGES		(TOTAL AREA) 42.67	20.14	25.28	36.72

Table B.4

ESTIMATED REFUSE QUANTITIES FOR CENSUS TRACTS IN ERIE COUNTY OUTSIDE CITY OF BUFFALO, 1966 (TONS PER YEAR)

CENSUS TRACT	POLITICAL SUBDIVISION	COORDINATES	REFUSE RESIDENTIAL	REFUSE COMMERCIAL/ INDUSTRIAL	TOTAL COMBUSTIBLE	TOTAL REFUSE
73A	GRAND ISLAND (T)	0.0 15.8	2,203	--	2,203	2,203
73B	GRAND ISLAND (T)	- 2.3 13.8	3,797	2,400	4,997	6,197
74	TONAWANDA (C)	4.34 15.95	622	--	622	622
75	TONAWANDA (C)	3.85 15.75	1,007	--	1,007	1,007
76	TONAWANDA (C)	4.29 15.05	2,527	--	2,527	2,527
77	TONAWANDA (C)	3.45 15.49	3,363	20,105	13,416	23,468
78	TONAWANDA (C)	2.50 15.04	3,981	23,806	15,884	27,787
79A	TONAWANDA (T)	5.63 15.08	9,714	--	9,714	9,714
79B	TONAWANDA (T)	5.75 13.40	5,595	--	5,595	5,595
80A	TONAWANDA (T)	5.90 12.60	4,509	--	4,509	4,509
80B	TONAWANDA (T)	5.48 11.90	7,362	--	7,362	7,362
81A	TONAWANDA (T)	4.34 13.76	3,788	--	3,788	3,788
81B	TONAWANDA (T)	4.50 12.65	2,942	--	2,942	2,942
82A	TONAWANDA (T)	3.50 13.80	1,829	--	1,829	1,829
82B	TONAWANDA (T)	3.50 12.69	2,620	--	2,620	2,620
83	TONAWANDA (T)	2.10 13.84	2,346	15,211	9,952	17,557
84	TONAWANDA (T)	1.46 12.45	2,078	13,478	8,817	15,556
85	KENMORE (V)	4.38 11.50	1,603	--	1,603	1,603
86	KENMORE (V)	4.30 11.93	2,920	--	2,920	2,920
87	KENMORE (V)	3.75 11.90	3,248	--	3,248	3,248
88	KENMORE (V)	3.25 11.80	2,446	--	2,446	2,446
89	WILLIAMSVILLE (V)	11.00 11.70	3,315	3,780	5,205	7,095
90	AMHERST (T)	11.30 16.40	3,525	--	3,525	3,525
91A	AMHERST (T)	7.50 16.70	942	--	942	942
91B	AMHERST (T)	7.40 14.20	1,021	--	1,021	1,021
91C	AMHERST (T)	9.60 14.20	4,756	--	4,756	4,756
91D	AMHERST (T)	8.80 13.30	1,943	--	1,943	1,943
92	AMHERST (T)	7.20 13.60	2,323	2,630	3,638	4,953
93A	AMHERST (T)	6.79 12.14	3,660	4,183	5,752	7,843
93B	AMHERST (T)	7.36 12.57	2,053	2,347	3,227	4,400
94A	AMHERST (T)	8.10 12.35	3,774	--	3,774	3,774
94B	AMHERST (T)	9.80 12.30	2,782	--	2,782	2,782
95A	AMHERST (T)	8.10 11.30	3,437	--	3,437	3,437
95B	AMHERST (T)	9.85 11.19	4,461	5,060	6,991	9,521
96	AMHERST (T)	12.45 11.78	2,008	--	2,008	2,008
97	DEPEW (V) ALSO 145	12.60 8.39	4,317	--	4,317	4,317
98	DEPEW (V)	12.91 7.40	895	--	895	895
99	SLOAN (V)	8.34 6.55	2,556	3,188	4,150	5,744
100A	CHEEKTOWAGA (T)	11.70 10.10	2,380	--	2,380	2,380
100B	CHEEKTOWAGA (T)	11.95 9.14	5,365	3,596	7,163	8,961
101A	CHEEKTOWAGA (T)	9.60 10.06	6,360	--	6,360	6,360
101B	CHEEKTOWAGA (T)	9.50 9.20	2,883	--	2,883	2,883

Table B.4 (Cont.)

ESTIMATED REFUSE QUANTITIES FOR CENSUS TRACTS IN ERIE COUNTY OUTSIDE CITY OF BUFFALO, 1966 (TONS PER YEAR)

CENSUS TRACT	POLITICAL SUBDIVISION	COORDINATES	REFUSE		TOTAL	
			RESIDENTIAL	COMMERCIAL/ INDUSTRIAL	COMBUSTIBLE	REFUSE
102	CHEEKTOWAGA (T)	8.33 9.74	4,385	5,469	7,120	9,854
103	CHEEKTOWAGA (T)	8.02 8.10	874	1,090	1,419	1,964
104	CHEEKTOWAGA (T)	8.40 7.82	1,482	--	1,482	1,482
105	CHEEKTOWAGA (T)	8.50 8.32	1,529	1,908	2,483	3,437
106	CHEEKTOWAGA (T)	9.72 8.70	1,830	2,283	1,141	4,113
107	CHEEKTOWAGA (T)	9.39 7.80	2,174	2,712	1,356	4,886
108	CHEEKTOWAGA (T)	11.72 6.38	3,261	--	3,261	3,261
109	CHEEKTOWAGA (T)	9.70 6.38	3,700	4,615	2,307	8,315
110	CHEEKTOWAGA (T)	8.71 5.40	1,294	--	1,294	1,294
111	CHEEKTOWAGA (T)	8.30 5.70	1,715	2,139	2,785	3,854
112	WEST SENECA (T)	11.84 3.82	1,904	--	1,904	1,904
113	WEST SENECA (T)	9.02 4.15	2,440	--	2,440	2,440
114	WEST SENECA (T)	8.05 3.45	1,547	--	1,547	1,547
115	WEST SENECA (T)	8.70 3.34	918	--	918	918
116	WEST SENECA (T)	9.53 2.90	1,204	--	1,204	1,204
117	WEST SENECA (T)	9.20 2.35	2,333	--	2,333	2,333
118	WEST SENECA (T)	11.65 2.48	1,703	--	1,703	1,703
119	WEST SENECA (T)	12.12 1.58	2,751	12,300	8,901	15,051
120A	WEST SENECA (T)	8.66 1.17	3,140	--	3,140	3,140
120B	WEST SENECA (T)	10.29 0.73	3,060	--	3,060	3,060
121	LACKAWANNA (C)	5.35 1.82	933	1,050	1,458	1,983
122	LACKAWANNA (C)	5.10 0.99	2,207	--	2,207	2,207
123	LACKAWANNA (C)	6.10 1.30	2,061	2,320	3,221	4,381
124	LACKAWANNA (C)	6.05 0.55	1,689	1,900	2,639	3,589
125	LACKAWANNA (C)	7.60 1.15	3,918	--	3,918	3,918
126	LACKAWANNA (C)	6.95 0.79	1,093	1,230	1,708	2,323
127	LACKAWANNA (C)	6.60 1.59	99	--	99	99
128	BLASDELL (V)	5.8 -0.5	1,446	--	1,446	1,446
129	HAMBURG (T)	7.0 -1.9	2,767	--	2,767	2,767
130	HAMBURG (T)	5.5 -1.8	1,597	35,000	19,097	36,597
131	HAMBURG (T)	2.2 -4.9	4,505	--	4,505	4,505
132	HAMBURG (V)	4.7 -6.1	3,058	--	3,058	3,058
133	HAMBURG (V)	6.0 -5.9	1,486	--	1,486	1,486
134	HAMBURG (V)	4.8 -4.9	2,141	--	2,141	2,141
135	ORCHARD PARK (T)	10.2 -4.9	3,427	--	3,427	3,427
136	ORCHARD PARK (V)	10.3 -2.7	1,962	4,000	3,962	5,962
137	ORCHARD PARK (T)	10.2 -1.1	4,611	--	4,611	4,611
138	AURORA (T)	15.8 -4.4	5,392	--	5,392	5,392
139	EAST AURORA (V)	16.8 -2.8	2,277	4,270	2,135	4,270
140	EAST AURORA (V)	16.9 -2.2	2,831	3,430	1,715	6,261
141A	ELMA (T)	17.2 1.4	2,159	900	2,609	3,059
141B	ELMA (T)	14.2 1.1	2,541	1,000	3,041	3,541

Table B.4 (Cont.)

ESTIMATED REFUSE QUANTITIES FOR CENSUS TRACTS IN ERIE COUNTY OUTSIDE CITY OF BUFFALO, 1966 (TONS PER YEAR)

CENSUS TRACT	POLITICAL SUBDIVISION	COORDINATES		REFUSE		TOTAL	
				RESIDENTIAL	COMMERCIAL/ INDUSTRIAL	COMBUSTIBLE	REFUSE
142A	LANCASTER (T)	15.8	9.1	3,388	--	3,388	3,388
142B	LANCASTER (T)	15.8	5.5	2,124	--	2,124	2,124
143	LANCASTER (V)	14.1	6.4	4,474	3,400	6,174	7,874
144	LANCASTER (V)	14.1	7.3	3,688	2,800	5,088	6,488
145	DEPEW(T)(ALSO 97 & 98)	13.95	8.10	4,326	--	4,326	4,326
146A	CLARENCE (T)	14.3	11.4	2,022	3,600	3,822	5,622
146B	CLARENCE (T)	14.2	14.2	1,450	--	1,450	1,450
147	CLARENCE (T)	16.9	16.1	2,728	--	2,728	2,728
148	NEWSTEAD (T)	21.8	15.4	2,800	1,300	3,450	4,100
149	ALDEN (T)	21.9	8.0	3,700	2,000	4,700	5,700
150	MARILLA (T)	21.2	1.7	1,300	600	1,600	1,900
150	WALES (T)	21.9	-4.4	1,100	600	1,400	1,700
150	HOLLAND (T)	21.9	-10.7	1,100	600	1,400	1,700
151	COLDEN (T)	15.8	-10.7	1,000	600	1,300	1,600
151	SARDINIA (T)	21.0	-15.3	1,000	500	1,250	1,500
152	BOSTON (T)	9.8	-10.7	2,600	1,300	3,250	3,900
153	EDEN (T)	3.6	-10.8	2,500	1,600	3,300	4,100
154	EVANS (T)	-2.5	-9.0	4,317	--	4,317	4,317
155	EVANS (T)	-3.5	-12.3	5,983	2,800	7,383	8,783
156	BRANT (T)	-3.9	-15.3	1,350	500	1,600	1,850
157	NORTH COLLINS (T)	4.3	-16.8	1,200	800	1,600	2,000
158	CONCORD (T)	12.6	-18.2	1,267	--	1,267	1,267
159	SPRINGVILLE (V)	14.6	-21.0	1,733	1,500	2,483	3,233
160	COLLINS (T)	4.3	-22.4	1,521	1,700	2,371	3,221
161	GOWANDA STATE HOSP.	0.9	-22.6	1,379	--	1,379	1,379
162	CATTARAUGUS IND.RES.	-3.2	-18.1	400	--	400	400
	TOTALS			293,150	213,600	399,950	506,750

Table B.5

ESTIMATED REFUSE QUANTITIES PER SQUARE MILE FOR CENSUS TRACTS IN ERIE COUNTY OUTSIDE CITY OF BUFFALO, 1966

(TONS PER DAY PER SQUARE MILE)

CENSUS TRACT	POLITICAL SUBDIVISION	COORDINATES		AREA (SQ.MI.)	TOTAL	
					COMBUSTIBLE	REFUSE
73A	GRAND ISLAND (T)	0.0	15.8	16.9	0.50	0.50
73B	GRAND ISLAND (T)	-2.3	13.8	18.3	1.05	1.30
74	TONAWANDA (C)	4.34	15.95	0.72	3.32	3.32
75	TONAWANDA (C)	3.85	15.75	0.23	16.84	16.84
76	TONAWANDA (C)	4.29	15.05	0.67	14.51	14.51
77	TONAWANDA (C)	3.45	15.49	0.69	74.78	130.81
78	TONAWANDA (C)	2.50	15.04	1.39	43.95	76.89
79A	TONAWANDA (T)	5.63	15.08	3.80	9.83	9.83
79B	TONAWANDA (T)	5.75	13.40	1.45	14.84	14.84
80A	TONAWANDA (T)	5.90	12.60	1.09	15.91	15.91
80B	TONAWANDA (T)	5.48	11.90	1.48	19.13	19.13
81A	TONAWANDA (T)	4.34	13.76	1.29	11.29	11.29
81B	TONAWANDA (T)	4.50	12.65	0.75	15.09	15.09
82A	TONAWANDA (T)	3.50	13.80	1.10	6.40	6.40
82B	TONAWANDA (T)	3.50	12.69	0.60	16.79	16.79
83	TONAWANDA (T)	2.10	13.84	3.82	10.02	17.68
84	TONAWANDA (T)	1.46	12.45	4.62	7.34	12.95
85	KENMORE (V)	4.38	11.50	0.32	19.27	19.27
86	KENMORE (V)	4.30	11.93	0.44	25.52	25.52
87	KENMORE (V).	3.75	11.90	0.32	39.04	39.04
88	KENMORE (V)	3.25	11.80	0.32	29.40	29.40
89	WILLIAMSVILLE (V)	11.00	11.70	1.20	16.68	22.74
90	AMHERST (T)	11.30	16.40	18.9	0.72	0.72
91A	AMHERST (T)	7.50	16.70	8.27	0.44	0.44
91B	AMHERST (T)	7.40	14.20	3.51	1.12	1.12
91C	AMHERST (T)	9.60	14.20	5.96	3.07	3.07
91D	AMHERST (T)	8.80	13.30	2.16	3.46	3.46
92	AMHERST (T)	7.20	13.60	2.49	5.02	7.65
93A	AMHERST (T)	6.79	12.14	0.37	59.79	81.53
93B	AMHERST (T)	7.36	12.57	0.79	15.71	21.42
94A	AMHERST (T)	8.10	12.35	1.20	12.10	12.10
94B	AMHERST (T)	9.80	12.30	1.44	7.43	7.43
95A	AMHERST (T)	8.10	11.30	1.19	11.11	11.11
95B	AMHERST (T)	9.85	11.19	1.61	16.70	22.74
96	AMHERST (T)	12.45	11.78	4.40	1.76	1.76
97	DEPEW (V) } ALSO 145	12.60	8.39	1.76	9.43	9.43
98	DEPEW (V) } ALSO 145	12.91	7.40	1.34	2.57	2.57
99	SLOAN (V)	8.34	6.55	0.70	22.80	31.56
100A	CHEEKTOWWGA (T)	11.70	10.10	2.76	3.32	3.32
100B	CHEEKTOWWGA (T)	11.95	9.14	1.85	14.89	18.63
101A	CHEEKTOWAGA (T)	9.60	10.06	1.51	16.20	16.20
101B	CHEEKTOWAGA (T)	9.50	9.20	0.86	12.89	12.89

Table B.5 (Cont.)

ESTIMATED REFUSE QUANTITIES PER SQUARE MILE FOR CENSUS TRACTS IN ERIE COUNTY OUTSIDE CITY OF BUFFALO, 1966 (TONS PER DAY PER SQUARE MILE)

CENSUS TRACT	POLITICAL SUBDIVISION	COORDINATES		AREA (SQ.MI.)	TOTAL	
					COMBUSTIBLE	REFUSE
102	CHEEKTOWAGA (T)	8.33	9.74	1.61	17.91	23.54
103	CHEEKTOWAGA (T)	8.02	8.10	0.39	13.99	19.37
104	CHEEKTOWAGA (T)	8.40	7.82	0.16	35.63	35.63
105	CHEEKTOWAGA (T)	8.50	8.32	0.59	16.19	22.41
106	CHEEKTOWAGA (T)	9.72	8.70	0.47	24.32	33.66
107	CHEEKTOWAGA (T)	9.39	7.80	2.18	6.23	8.62
108	CHEEKTOWAGA (T)	11.72	6.38	7.82	1.60	1.60
109	CHEEKTOWAGA (T)	9.70	6.38	2.69	8.59	11.89
110	CHEEKTOWAGA (T)	8.71	5.40	0.39	12.76	12.76
111	CHEEKTOWAGA (T)	8.30	5.70	0.42	25.50	35.29
112	WEST SENECA (T)	11.84	3.82	4.77	1.54	1.54
113	WEST SENECA (T)	9.02	4.15	2.45	3.83	3.83
114	WEST SENECA (T)	8.05	3.45	0.31	19.19	19.19
115	WEST SENECA (T)	8.70	3.34	0.92	3.84	3.84
116	WEST SENECA (T)	9.53	2.90	0.74	6.25	6.25
117	WEST SENECA (T)	9.20	2.35	1.28	7.01	7.01
118	WEST SENECA (T)	11.65	2.48	1.51	4.34	4.34
119	WEST SENECA (T)	12.12	1.58	3.69	9.28	15.69
120A	WEST SENECA (T)	8.66	1.17	2.68	4.51	4.51
120B	WEST SENECA (T)	10.29	0.73	3.15	3.74	3.74
121	LACKAWANNA (C)	5.35	1.82	0.44	12.74	17.33
122	LACKAWANNA (C)	5.10	0.99	1.99	4.27	4.27
123	LACKAWANNA (C)	6.10	1.30	0.49	25.28	34.39
124	LACKAWANNA (C)	6.05	0.55	0.60	16.92	23.01
125	LACKAWANNA (C)	7.60	1.15	1.44	10.46	10.46
126	LACKAWANNA (C)	6.95	0.79	1.07	6.14	8.35
127	LACKAWANNA (C)	6.60	1.59	0.04	9.52	9.52
128	BLASDELL (V)	5.80	-0.5	0.89	6.25	6.25
129	HAMBURG (T)	7.0	-1.9	5.92	1.80	1.80
130	HAMBURG (T)	5.5	-1.8	4.82	15.24	29.20
131	HAMBURG (T)	2.2	-4.9	8.99	1.93	1.93
132	HAMBURG (V)	4.7	-6.1	19.60	0.60	0.60
133	HAMBURG (V)	6.0	-5.9	0.56	10.21	10.21
134	HAMBURG (V)	4.8	-4.9	1.41	5.84	5.84
135	ORCHARD PARK (T)	10.2	-4.9	24.7	0.53	0.53
136	ORCHARD PARK (V)	10.3	-2.7	1.28	11.91	17.91
137	ORCHARD PARK (T)	10.2	-1.1	12.8	1.39	1.39
138	AURORA (T)	15.8	-4.4	34.2	0.61	0.61
139	EAST AURORA (V)	16.8	-2.8	1.14	14.89	22.09
140	EAST AURORA (V)	16.9	-2.2	1.43	12.23	16.84
141A	ELMA (T)	17.2	1.4	18.7	0.54	0.63
141B	ELMA (T)	14.2	1.1	15.9	0.74	0.86

Table B.5 (Cont.)

ESTIMATED REFUSE QUANTITIES PER SQUARE MILE FOR CENSUS TRACTS IN ERIE COUNTY OUTSIDE CITY OF BUFFALO, 1966

(TONS PER DAY PER SQUARE MILE)

CENSUS TRACT	POLITICAL SUBDIVISION	COORDINATES		AREA (SQ.MI.)	TOTAL	
					COMBUSTIBLE	REFUSE
142A	LANCASTER (T)	15.8	9.1	21.9	0.60	0.60
142B	LANCASTER (T)	15.8	5.5	13.7	0.60	0.60
143	LANCASTER (V)	14.1	6.4	1.21	19.62	25.03
144	LANCASTER (V)	14.1	7.3	1.52	12.87	16.42
145	DEPEW(T)(ALSO 97 & 98)	13.95	8.1	1.70	9.79	9.79
146A	CLARENCE (T)	14.3	11.4	4.19	3.51	5.16
146B	CLARENCE (T)	14.2	14.2	11.2	0.50	0.50
147	CLARENCE (T)	16.9	16.1	38.5(-)	0.27	0.27
148	NEWSTEAD (T)	21.8	15.4	51.2	0.26	0.31
149	ALDEN (T)	21.9	8.0	34.6	0.52	0.63
150	MARILLA (T)	21.2	1.7	27.5	0.22	0.27
150	WALES (T)	21.9	-4.4	36.0	0.15	0.18
150	HOLLAND (T)	21.9	-10.7	36.0	0.15	0.18
151	COLDEN (T)	15.8	-10.7	36.0	0.14	0.17
151	SARDINIA (T)	21.0	-15.3	50.8	0.09	0.11
152	BOSTON (T)	9.8	-10.7	35.7	0.35	0.42
153	EDEN (T)	3.6	-10.8	39.9	0.32	0.39
154	EVANS (T)	-2.5	-9.0	19.7	0.84	0.84
155	EVANS (T)	-3.5	-12.3	22.2	1.28	1.52
156	BRANT (T)	-3.9	-15.3	25.9	0.24	0.27
157	NORTH COLLINS (T)	4.3	-16.8	43.3	0.14	0.17
158	CONCORD (T)	12.6	-18.2	67.0	0.07	0.07
159	SPRINGVILLE (V)	14.6	-21.0	3.44	2.78	3.61
160	COLLINS (T)	4.3	-22.4	46.6	0.20	0.27
161	GOWANDA STATE HOSP.	0.9	-22.6	1.07	4.96	4.96
162	CATTARAUGUS IND.RES.	-3.2	-18.1	13.7	0.11	0.11

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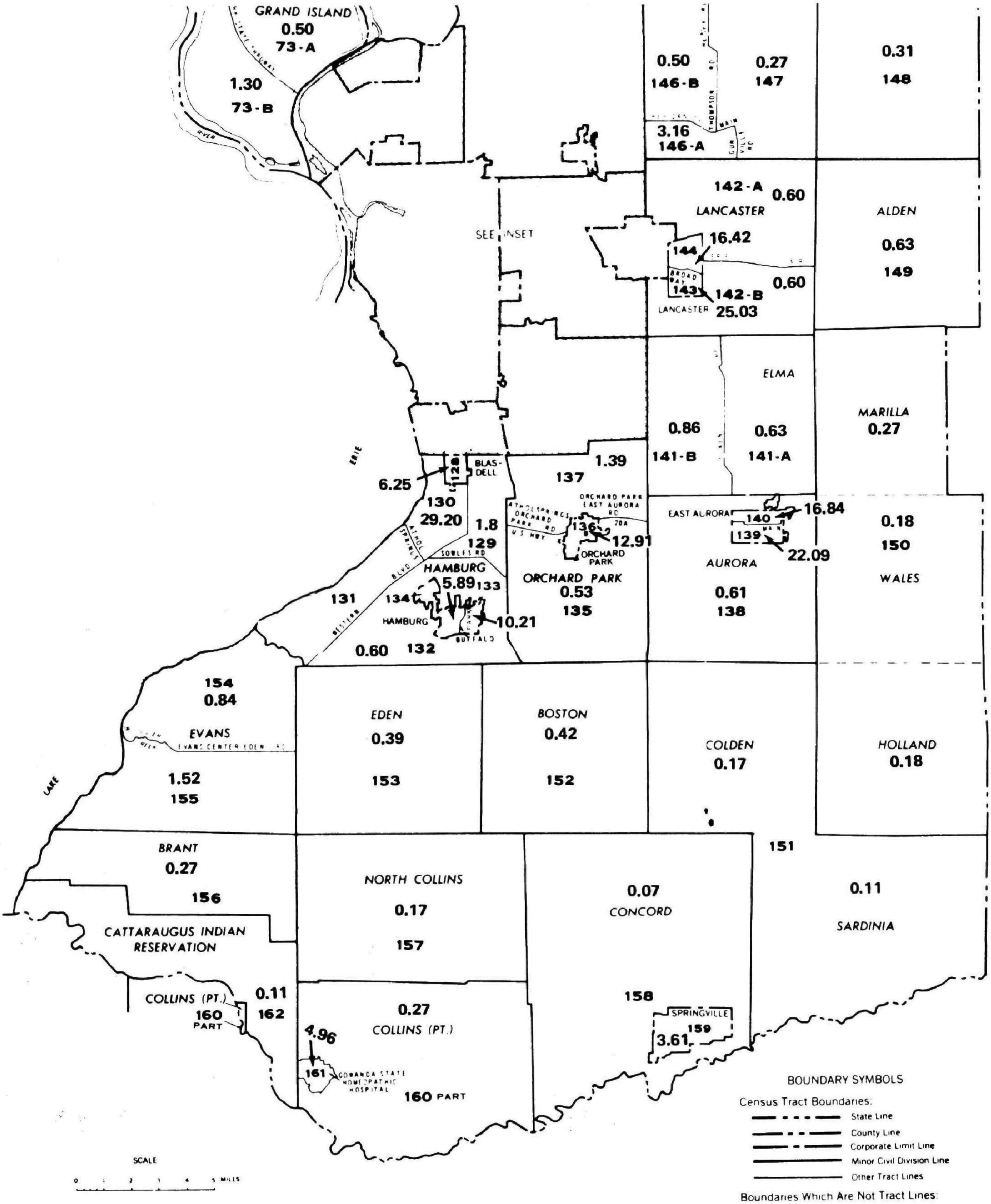

Figure B.2 ESTIMATED TOTAL REFUSE QUANTITIES PER SQUARE MILE FOR CENSUS TRACTS IN ERIE COUNTY, NEW YORK, WHICH ARE OUTSIDE BUFFALO CITY AND ADJACENT AREA, 1966 (TONS PER DAY PER SQUARE MILE)

The above are samples of current changes in solid waste quantities and characteristics which have been observed but whose ultimate magnitudes are difficult to forecast. It can be expected that many new developments affecting solid waste are likely to take place by the year 2000.

Two major factors which have a profound influence on the quantity of solid waste generation are the projected population of the region and the gross regional product. The problems of deriving projections of the U.S. population and the gross national product out to the year 2000 are exceedingly difficult but are considered less difficult then making similar types of projections at the regional level. With the increased mobility of both the U.S. population and economic activity, the scope and nature of this migration with respect to a particular region is a large unknown.

Although the magnitude of these changes cannot be accurately predicted the directions of these changes are clearly discernible. Qualitatively, it can be expected that there will be increases in both the refuse generated per capita per unit time, and the amounts of solid waste produced by the industrial and service sectors will increase in some relationship with increases in the gross national product. For purposes of this study it was decided to accept and use the planning factors indicated within the National Academy of Sciences - National Research Council Study (Ref. 3).

(a) The residential per capita generation of solid waste will increase by approximately two percent per annum*

(b) The commercial and industrial generation of solid wastes will increase annually by four percent.

This rate of increase appears to be representative of the increases experienced by the City of Buffalo since 1960.

Utilizing the current estimates of solid waste generation in the Buffalo SMSA, the projections of population changes within the census tracts of the region; the assumption of no significant changes in the size of the industrial, commercial and service sectors; and the above projection factors, the following tables (Tables B.6 through B.12), represent an estimate of future solid waste generation. For the purposes of the analytical planning tools described in Sections 3 and 4 within the report, having projections for five year increments out to the year 2000 appear adequate. The development of comparable estimates on an annual basis could in no way refine the estimates in view of the broad assumptions which were introduced as well as the many unknown and intangible factors.

This basic information is apparently critical for purposes of planning and research, and it is of importance that significant time and effort be devoted within the Solid Wastes Program to the development of projection models which can be used at the regional level. However, as has been mentioned earlier, efforts should be made to obtain a more accurate estimate of the current types and quantities of solid waste generated, and this information should be categorized as to residential, commercial and industrial sources. Using this information base, a range of projections should be made using a range of assumptions pertaining to changes in quantity and type of solid waste generated and the sensitivity of the "recommended" facility alternatives should be tested for the range of projections utilized.

Table B.6
ANNUAL REFUSE TONNAGE BY CENSUS TRACTS
CITY OF BUFFALO

	1966	1970	1975	1980	1985	1990	1995	2000
1	1518	1570	1688	1830	2007	2216	2464	2782
2	3144	3252	3497	3792	4158	4591	5103	5762
3	636	657	707	767	841	928	1032	1165
4	400	414	445	483	530	585	650	734
5	1576	1630	1753	1901	2085	2302	2559	2889
6	3444	3561	3829	4153	4554	5028	5589	6311
7	2341	2421	2603	2823	3096	3418	3800	4291
8	3341	3455	3715	4029	4418	4878	5422	6123
9	1543	1596	1716	1861	2041	2254	2505	2829
10	3856	3988	4289	4650	5099	5630	6259	7067
11	1962	2029	2182	2366	2595	2865	3185	3596
12	2383	2465	2651	2874	3152	3480	3869	4368
13	1465	1516	1630	1767	1938	2140	2379	2686
14	6984	7222	7766	8421	9234	10196	11334	12798
15	3664	3790	4075	4419	4845	5350	5947	6715
16	3854	3986	4286	4647	5096	5627	6255	7063
17	1805	1867	2008	2177	2387	2636	2930	3309
18	731	756	813	881	966	1067	1186	1339
19	2058	2128	2288	2481	2721	3004	3340	3771
20	1183	1224	1316	1427	1565	1728	1921	2169
21	544	562	605	656	719	794	883	997
22	1185	1225	1317	1429	1567	1730	1923	2171
23	2228	2305	2478	2687	2947	3254	3617	4084
24	3910	4044	4348	4715	5170	5709	6346	7166
25	10691	11056	11889	12892	14136	15608	17350	19591
26	1659	1716	1845	2000	2194	2422	2693	3040
27	7013	7253	7799	8457	9273	10239	11382	12852
28	3897	4031	4334	4700	5154	5690	6326	7143
29	2882	2981	3205	3476	3811	4208	4678	5282
30	1688	1746	1878	2036	2233	2465	2740	3094
31	5326	5509	5923	6423	7043	7776	8645	9761
32	6932	7169	7708	8359	9166	10120	11250	12703
33	6839	7072	7605	8246	9043	9984	11099	12532
34	3094	3200	3441	3731	4091	4517	5021	5670
35	4327	4475	4812	5218	5722	6318	7023	7930
36	3045	3149	3386	3672	4027	4446	4942	5581
37	2900	2999	3225	3497	3835	4234	4707	5315
38	1692	1750	1881	2040	2237	2470	2746	3101
39	2620	2710	2914	3159	3464	3825	4252	4801
40	4215	4360	4688	5083	5574	6154	6841	7725

Table B.6 (Cont.)

ANNUAL REFUSE TONNAGE BY CENSUS TRACTS
CITY OF BUFFALO (CONT.)

	1966	1970	1975	1980	1985	1990	1995	2000
41	3129	3236	3479	3773	4137	4568	5078	5734
42	2004	2073	2229	2417	2650	2926	3253	3673
43	3206	3315	3565	3866	4239	4680	5203	5875
44	3581	3703	3982	4318	4735	5228	5812	6562
45	3555	3677	3954	4287	4701	5191	5770	6516
46	3192	3301	3550	3849	4221	4661	5181	5850
47	3129	3236	3480	3773	4138	4568	5079	5735
48	2259	2336	2512	2724	2987	3298	3666	4140
49	2593	2682	2884	3127	3429	3786	4209	4753
50	1483	1533	1649	1788	1961	2165	2406	2717
51	2704	2796	3007	3260	3575	3947	4388	4955
52	3916	4050	4354	4722	5178	5717	6355	7176
53	447	462	497	539	591	653	726	820
54	2079	2150	2312	2507	2749	3036	3375	3811
55	2469	2554	2746	2978	3265	3605	4008	4526
56	2597	2686	2888	3132	3434	3792	4215	4760
57	2018	2088	2245	2434	2669	2947	3276	3699
58	5224	5403	5810	6300	6908	7627	8479	9574
59	2543	2630	2828	3066	3362	3712	4127	4660
60	2729	2822	3035	3291	3609	3984	4429	5002
61	2593	2682	2884	3127	3429	3786	4209	4753
62	2910	3010	3237	3510	3849	4249	4724	5334
63A	2822	2919	3139	3404	3732	4121	4581	5173
63B	2111	2183	2347	2546	2791	3082	3426	3869
64	501	518	557	604	662	731	813	918
65A	1439	1488	1600	1735	1903	2101	2335	2637
65B	1957	2024	2176	2360	2588	2857	3176	3587
66A	1850	1913	2057	2230	2446	2700	3002	3390
66B	1253	1296	1394	1511	1657	1830	2034	2297
67	3837	3968	4267	4627	5073	5602	6227	7031
68	3188	3297	3545	3844	4215	4654	5174	5842
69	6053	6260	6731	7299	8004	8837	9823	11092
70	3060	3165	3403	3690	4046	4468	4966	5608
71	6590	6816	7329	7947	8715	9622	10696	12078
72	733	758	815	884	969	1070	1189	1343

Table B.7
ANNUAL TONS OF REFUSE PER CAPITA
CITY OF BUFFALO

	1966	1970	1975	1980	1985	1990	1995	2000
1	0.449	0.486	0.537	0.593	0.655	0.723	0.798	0.881
2	0.449	0.486	0.537	0.593	0.654	0.723	0.798	0.881
3	0.450	0.487	0.537	0.593	0.655	0.723	0.798	0.882
4	0.330	0.357	0.394	0.435	0.481	0.531	0.586	0.647
5	0.330	0.357	0.394	0.435	0.480	0.530	0.586	0.647
6	0.449	0.486	0.537	0.593	0.654	0.723	0.798	0.881
7	0.423	0.457	0.505	0.557	0.616	0.680	0.750	0.828
8	0.437	0.473	0.522	0.576	0.636	0.703	0.776	0.857
9	0.436	0.472	0.521	0.575	0.635	0.701	0.774	0.854
10	0.423	0.457	0.505	0.558	0.616	0.680	0.750	0.829
11	0.413	0.447	0.493	0.544	0.601	0.663	0.733	0.809
12	0.385	0.416	0.460	0.508	0.560	0.619	0.683	0.754
13	0.445	0.482	0.532	0.587	0.648	0.716	0.790	0.872
14	0.763	0.826	0.912	1.007	1.111	1.227	1.355	1.496
15	0.390	0.423	0.467	0.515	0.569	0.628	0.693	0.765
16	0.452	0.489	0.540	0.596	0.658	0.726	0.802	0.885
17	0.464	0.502	0.554	0.612	0.675	0.746	0.823	0.909
18	0.342	0.371	0.409	0.452	0.499	0.551	0.608	0.671
19	0.415	0.450	0.497	0.548	0.605	0.668	0.738	0.815
20	0.476	0.515	0.569	0.628	0.693	0.766	0.845	0.933
21	0.454	0.491	0.543	0.599	0.661	0.730	0.806	0.890
22	0.415	0.450	0.496	0.548	0.605	0.668	0.738	0.814
23	0.440	0.476	0.526	0.580	0.641	0.707	0.781	0.862
24	0.472	0.511	0.564	0.623	0.688	0.760	0.839	0.926
25	1.145	1.240	1.369	1.511	1.668	1.842	2.034	2.245
26	0.390	0.423	0.467	0.515	0.569	0.628	0.693	0.765
27	0.469	0.508	0.561	0.619	0.683	0.755	0.833	0.920
28	0.484	0.524	0.578	0.638	0.705	0.778	0.859	0.949
29	0.432	0.467	0.516	0.569	0.629	0.694	0.766	0.846
30	0.432	0.468	0.517	0.571	0.630	0.695	0.768	0.848
31	0.462	0.500	0.552	0.609	0.673	0.743	0.820	0.905
32	0.450	0.487	0.538	0.594	0.655	0.724	0.799	0.882
33	0.433	0.469	0.518	0.572	0.631	0.697	0.770	0.850
34	0.434	0.470	0.518	0.572	0.632	0.698	0.770	0.851
35	0.433	0.468	0.517	0.571	0.630	0.696	0.768	0.848
36	0.435	0.470	0.519	0.574	0.633	0.699	0.772	0.852
37	0.432	0.468	0.517	0.570	0.630	0.695	0.768	0.848
38	0.432	0.468	0.517	0.571	0.630	0.696	0.768	0.848
39	0.440	0.476	0.526	0.581	0.641	0.708	0.781	0.863
40	0.453	0.490	0.541	0.598	0.660	0.729	0.805	0.888

Table B.7 (Cont.)

ANNUAL TONS OF REFUSE PER CAPITA
CITY OF BUFFALO (CONT.)

	1966	1970	1975	1980	1985	1990	1995	2000
41	0.389	0.421	0.465	0.513	0.566	0.625	0.690	0.762
42	0.410	0.444	0.490	0.541	0.598	C.660	0.728	0.804
43	0.437	0.473	0.523	0.577	0.637	0.703	0.777	C.857
44	0.389	0.421	0.465	0.513	C.566	0.625	0.690	0.762
45	0.467	0.505	0.558	0.616	0.680	0.750	0.829	C.915
46	0.459	0.497	0.548	0.605	0.668	0.738	0.815	0.900
47	0.441	0.477	0.527	0.581	0.642	0.709	0.782	0.864
48	0.416	C.450	0.497	0.548	0.606	0.669	0.738	C.815
49	0.285	0.309	0.341	0.377	0.416	0.459	0.507	0.560
50	0.425	0.460	0.508	0.561	0.619	0.684	0.755	0.833
51	0.444	0.481	0.531	0.586	0.647	0.714	0.788	0.871
52	0.418	0.453	0.500	0.552	0.609	0.673	0.743	0.820
53	0.387	0.419	0.463	0.511	0.564	0.623	0.687	0.759
54	0.404	0.437	0.483	0.533	0.589	0.650	0.717	0.792
55	0.423	0.458	0.505	0.558	0.616	0.680	0.751	0.829
56	0.428	0.464	0.512	0.565	0.624	0.689	0.761	C.840
57	0.496	0.536	0.592	0.654	0.722	0.797	0.880	0.972
58	0.496	0.536	0.592	0.654	0.722	0.797	C.880	0.972
59	0.495	0.536	0.592	0.654	0.722	0.797	0.880	0.971
60	0.347	C.374	0.415	0.458	0.506	0.558	0.616	0.681
61	0.337	0.364	0.402	0.444	0.490	0.541	0.598	C.660
62	0.556	C.602	0.665	0.734	0.810	0.894	0.987	1.090
63A	0.486	0.526	0.581	0.642	0.7C8	0.782	0.864	0.953
63B	0.543	0.587	0.648	0.716	0.791	0.873	0.964	1.064
64	0.500	0.541	0.597	0.659	0.728	0.804	0.888	0.980
65A	0.337	0.364	0.402	0.444	0.490	0.542	0.598	0.660
65B	0.482	C.522	0.576	0.636	0.702	0.775	0.856	0.945
66A	0.461	0.499	0.551	0.608	0.671	0.741	0.818	0.904
66B	0.482	0.522	0.576	0.636	0.702	0.775	0.856	0.945
67	0.483	0.523	C.578	0.638	0.704	0.777	0.858	0.948
68	0.502	0.544	0.600	0.663	0.732	0.808	0.892	0.985
69	0.459	0.497	0.549	0.606	0.669	0.738	0.815	0.900
70	0.469	0.508	0.561	C.619	0.684	0.755	0.833	0.920
71	0.511	0.553	0.611	0.675	0.745	0.822	C.908	1.002
72	0.355	0.384	0.424	0.468	0.517	0.571	0.631	0.696

Table B.8
ANNUAL TCNS OF REFUSE PER SQUARE MILE
CITY OF BUFFALO

	1966	1970	1975	1980	1985	1990	1995	200C
1	943	975	1048	1137	1246	1376	1530	1728
2	6289	6504	6994	7584	8316	9182	10207	11525
3	291	301	324	351	385	426	473	534
4	715	740	796	863	946	1045	1161	1311
5	1151	1190	1279	1387	1521	1680	1867	2109
6	7653	7915	8511	9229	10120	11173	12420	14025
7	5575	5765	6199	6722	7372	8139	9048	10216
8	777C	8036	8641	9370	10275	11344	12611	14240
9	7018	7258	7804	8462	9280	10245	11389	12861
10	4646	4805	5167	5603	6144	6783	7541	8515
11	3326	3440	3699	4011	4398	4856	5398	6096
12	3455	3573	3842	4166	4568	5044	5607	6331
13	1332	1378	1481	1606	1762	1945	2162	2442
14	13968	14445	15533	16843	18469	20392	22669	25597
15	8938	9244	9940	10778	11819	13049	14506	16380
16	6762	6993	7519	8154	8941	9871	10974	12391
17	3685	3811	4098	4444	4873	5380	5981	6753
18	2089	2160	2323	2519	2762	3049	3390	3828
19	4200	4344	4671	5065	5554	6132	6816	7697
20	1517	1569	1687	1830	2006	2215	2463	2781
21	1183	1223	1315	1426	1564	1727	1920	2168
22	4232	4377	4707	5104	5597	6179	6869	7756
23	4548	4704	5058	5485	6015	6641	7382	8336
24	5214	5392	5798	6287	6894	7612	8462	9555
25	17818	18427	19815	21486	23561	26013	28917	32653
26	9218	9534	10251	11116	12189	13458	14961	16893
27	10468	10826	11640	12622	13841	15282	16988	19183
28	7496	7752	8336	9039	9912	10943	12165	13736
29	8735	9033	9713	10533	11550	12752	14176	16007
30	3311	3424	3682	3993	4378	4834	5374	6068
31	8878	9181	9873	10705	11739	12961	14408	16269
32	10194	10543	11336	12292	13479	14882	16544	18681
33	9911	10250	11022	11952	13106	14470	16085	18163
34	5244	5424	5832	6324	6935	7656	8511	9611
35	6980	7219	7762	8417	9229	10190	11328	12791
36	5971	6176	6641	7201	7896	8718	9691	10943
37	6305	6521	7011	7603	8337	9205	10233	11554
38	7051	7292	7841	8502	9323	10294	11443	12921
39	4159	4301	4625	5015	5499	6072	6750	7622
40	5475	5662	6088	6602	7239	7993	8885	10033

Table B.8 (Cont.)

ANNUAL TONS OF REFUSE PER SQUARE MILE
CITY OF BUFFALO (CONT.)

	1966	1970	1975	1980	1985	1990	1995	2000
41	6135	6345	6823	7398	8113	8957	9957	11243
42	5011	5183	5573	6043	6627	7317	8133	9184
43	6821	7054	7586	8225	9020	9958	11070	12500
44	6069	6277	6750	7319	8026	8861	9851	11123
45	4558	4714	5069	5497	6027	6655	7398	8354
46	3990	4127	4438	4812	5277	5826	6476	7313
47	5047	5220	5613	6086	6674	7369	8191	9250
48	5648	5841	6281	6811	7469	8246	9167	10351
49	5764	5961	6410	6951	7622	8415	9355	10563
50	2908	3007	3233	3506	3845	4245	4719	5329
51	6009	6214	6682	7246	7945	8772	9752	11011
52	5844	6044	6499	7048	7728	8532	9485	10711
53	559	578	622	674	739	816	907	1025
54	2700	2793	3003	3256	3571	3943	4383	4949
55	4186	4329	4655	5048	5535	6111	6793	7671
56	3167	3276	3522	3820	4188	4624	5141	5805
57	5608	5800	6236	6762	7415	8187	9101	10277
58	7916	8187	8803	9546	10467	11557	12847	14507
59	5190	5367	5771	6258	6863	7577	8423	9511
60	3688	3814	4101	4447	4877	5385	5986	6759
61	5518	5707	6137	6654	7297	8056	8956	10113
62	7660	7922	8518	9237	10129	11183	12432	14038
63A	11762	12164	13080	14183	15553	17172	19089	21555
63B	5413	5598	6020	6528	7158	7903	8786	9921
64	2088	2160	2322	2518	2761	3049	3389	3827
65A	7575	7834	8424	9134	10016	11059	12293	13881
65B	6990	7229	7773	8429	9243	10205	11345	12810
66A	12333	12755	13715	14873	16309	18006	20016	22602
66B	7835	8103	8713	9448	10360	11439	12716	14359
67	7106	7349	7902	8568	9396	10374	11532	13022
68	9109	9420	10129	10984	12044	13298	14783	16692
69	12353	12776	13737	14896	16335	18035	20048	22638
70	5465	5652	6077	6590	7226	7978	8869	10015
71	9986	10327	11105	12042	13204	14579	16206	18300
72	1286	1330	1430	1551	1700	1877	2087	2357

Table B.9

ANNUAL REFUSE TONNAGE BY CENSUS TRACTS
ERIE COUNTY OUTSIDE BUFFALO

		1966	1970	1975	1980	1985	1990	1995	2000
GRI	73A	2202	2638	3496	4760	6108	7214	8311	9559
	73B	3797	4549	6027	8207	10531	12438	14329	16480
CTN	74	622	674	762	860	949	1048	1157	1278
	75	1006	1092	1233	1391	1536	1696	1873	2068
	76	2527	2742	3096	3494	3858	4260	4703	5193
	77	3362	3648	4120	4649	5133	5668	6258	6909
	78	3981	4320	4878	5505	6078	6711	7409	8181
TTN	79A	9714	10735	12275	14020	15480	17091	18869	20833
	79B	5594	6182	7069	8074	8915	9843	10867	11998
	80A	4508	4982	5697	6507	7184	7932	8757	9669
	80B	7362	8136	9303	10626	11732	12953	14301	15789
	81A	3788	4186	4787	5467	6036	6664	7358	8124
	81B	2942	3251	3718	4246	4688	5176	5715	6310
	82A	1829	2021	2311	2640	2914	3218	3553	3922
	82B	2620	2895	3311	3782	4175	4610	5090	5620
	83	2345	2592	2964	3385	3737	4126	4556	5030
	84	2078	2296	2626	2999	3312	3656	4037	4457
	85	1602	1770	2025	2312	2553	2819	3112	3436
	86	2919	3226	3689	4213	4652	5136	5671	6261
	87	3248	3589	4104	4688	5175	5714	6309	6966
	88	2446	2703	3091	3530	3897	4303	4751	5246
AMH	89	3314	4034	5155	6631	8419	9902	11453	13138
	90	3524	4290	5481	7051	8952	10528	12178	13969
	91A	942	1146	1465	1884	2392	2814	3255	3733
	91B	1020	1242	1587	2042	2593	3049	3527	4046
	91C	4756	5789	7397	9514	12080	14208	16433	18851
	91D	1943	2365	3022	3887	4935	5804	6714	7701
	92	2323	2827	3613	4647	5901	6940	8027	9208
	93A	3660	4455	5693	7322	9297	10935	12648	14508
	93B	2053	2499	3193	4107	5215	6134	7095	8138
	94A	3773	4593	5869	7549	9585	11273	13039	14957
	94B	2781	3385	4326	5564	7065	8309	9611	11025
	95A	3436	4183	5344	6875	8729	10266	11874	13621
	95B	4461	5429	6938	8924	11331	13326	15414	17681
	96	2007	2443	3122	4016	5100	5998	6937	7958
CHK	97	4317	5227	6512	7894	9027	10104	11308	12568
	98	894	1083	1349	1636	1870	2094	2343	2604
	99	2555	3094	3855	4673	5344	5981	6694	7440
	100A	2380	2882	3590	4352	4977	5571	6234	6929
	100B	5365	6496	8092	9810	11219	12557	14052	15619

Table B.9 (Cont.)
ANNUAL REFUSE TONNAGE BY CENSUS TRACTS
ERIE COUNTY OUTSIDE BUFFALO (CONT.)

		1966	1970	1975	1980	1985	1990	1995	2000
	101A	6360	7701	9593	11630	13299	14886	16659	18516
	101B	2883	3491	4349	5272	6029	6748	7552	8394
	102	4384	5309	6613	8018	9168	10262	11484	12765
	103	874	1058	1318	1598	1828	2046	2289	2545
	104	1481	1793	2234	2708	3097	3467	3880	4312
	105	1529	1851	2306	2796	3197	3579	4005	4452
	106	1830	2216	2760	3347	3827	4284	4794	5328
	107	2174	2632	3279	3975	4546	5088	5694	6329
	108	3260	3948	4918	5962	6818	7631	8540	9492
	109	3700	4480	5581	6766	7737	8660	9692	10772
	110	1293	1566	1951	2365	2704	3027	3387	3765
	111	1714	2076	2586	3136	3586	4013	4492	4992
WSN	112	1904	2279	3146	4515	5369	6139	6934	7742
	113	2439	2921	4031	5786	6879	7867	8885	9920
	114	1546	1851	2555	3667	4360	4986	5632	6288
	115	917	1098	1515	2175	2587	2958	3341	3730
	116	1203	1441	1989	2855	3394	3882	4384	4895
	117	2333	2793	3855	5533	6579	7523	8497	9487
	118	1703	2039	2814	4039	4803	5492	6203	6925
	119	2751	3294	4546	6525	7758	8871	10020	11187
	120A	3140	3759	5188	7446	8854	10124	11435	12767
	120B	3059	3663	5055	7256	8627	9865	11143	12441
LKA	121	932	1019	1152	1307	1480	1671	1874	2101
	122	2207	2412	2728	3093	3504	3955	4435	4972
	123	2061	2253	2547	2888	3273	3694	4142	4644
	124	1688	1845	2087	2366	2681	3026	3393	3804
	125	3918	4283	4843	5491	6221	7022	7874	8828
	126	1092	1194	1350	1531	1735	1958	2196	2461
	127	99	108	122	138	157	177	199	223
HAM	128	1446	1759	2330	3109	3977	4704	5483	6276
	129	2766	3364	4457	5947	7607	8999	10488	12006
	130	1596	1942	2573	3432	4391	5194	6053	6930
	131	4505	5479	7259	9684	12388	14655	17079	19551
	132	3058	3719	4928	6574	8410	9949	11594	13273
	133	1486	1807	2394	3194	4086	4834	5633	6449
	134	2140	2603	3449	4601	5886	6962	8114	9289
OPK	135	3426	4255	5729	7844	9778	11721	13622	15791
	136	1962	2437	3281	4492	5599	6712	7801	9043
	137	4611	5726	7710	10556	13159	15774	18332	21252
AUR	138	5392	6266	8072	10440	12932	16140	18848	21188

Table B.9 (Cont.)

ANNUAL REFUSE TONNAGE BY CENSUS TRACTS
ERIE COUNTY OUTSIDE BUFFALO (CONT.)

		1966	1970	1975	1980	1985	1990	1995	2000
	139	2277	2646	3409	4409	5462	6817	7960	8949
	140	2830	3289	4237	5480	6788	8473	9894	11123
ELM	141A	2158	2564	3539	4845	6039	7239	8413	9754
	141B	2541	3018	4165	5702	7108	8521	9903	11480
LAN	142A	3387	4154	5476	7255	8845	10871	12816	14711
	142B	2124	2605	3434	4550	5547	6817	8037	9226
	143	4473	5485	7231	9581	11680	14356	16925	19428
	144	3688	4522	5962	7899	9630	11836	13954	16017
	145	4326	5305	6993	9266	11296	13883	16367	18788
CLA	146A	2021	2380	3126	3922	4850	5832	6862	7926
	146B	1450	1708	2242	2814	3479	4184	4923	5686
	147	2728	3213	4219	5293	6545	7872	9261	10697
NEW	148	2799	3449	4352	5405	6565	7907	9296	10709
ALD	149	3699	4452	5617	7236	9016	10900	12800	14593
HCL	150	1099	1333	2012	2709	3410	4096	4887	5637
MAR	150	1299	1469	1839	2388	2901	3494	4179	4881
WAL	150	1099	1353	1942	2473	3034	3618	4217	4901
CDN	151	999	1237	1776	2262	2775	3309	3857	4483
SAR	151	999	1180	1407	1727	2161	2526	2944	3421
BCS	152	2599	3364	4804	6562	8030	9732	11555	13408
EDN	153	2499	2929	3678	4686	5913	7018	8289	9616
EVS	154	4317	4990	6296	8255	10554	12446	14619	16786
	155	5982	6915	8726	11440	14625	17249	20259	23263
BRA	156	1349	1731	2230	2814	3417	4116	4923	5749
NCL	157	1199	1444	1843	2348	2894	3434	4002	4651
CCN	158	1267	1532	1924	2451	3015	3642	4304	5029
	159	1732	2095	2631	3352	4124	4981	5886	6878
COL	160	1520	1779	2149	2680	3353	4138	4980	5840
	161	1379	1614	1950	2430	3041	3753	4518	5297
IND	162	399	459	457	373	330	296	276	277

Table B.10

ANNUAL TONS OF REFUSE PER CAPITA
CENSUS TRACTS IN ERIE COUNTY OUTSIDE BUFFALO

	1966	1970	1975	1980	1985	1990	1995	2000
GR ISLND	0.521	0.575	0.635	0.701	0.774	0.854	0.943	1.042
CY TWNDA	0.524	0.567	0.626	0.691	0.763	0.843	0.931	1.027
TN TWNDA	0.483	0.523	0.577	0.637	0.704	0.777	0.858	0.947
AMHERST	0.505	0.547	0.604	0.667	0.736	0.813	0.897	0.991
CHKTWAGA	0.465	0.504	0.556	0.614	0.678	0.748	0.826	0.912
W SENECA	0.484	0.524	0.578	0.638	0.705	0.778	0.859	0.949
LKAWANNA	0.418	0.452	0.499	0.551	0.609	0.672	0.742	0.819
HAMBURG	0.382	0.414	0.457	0.504	0.557	0.614	0.678	0.749
ORCHD PK	0.560	0.606	0.669	0.738	0.815	0.900	0.994	1.097
AURORA	0.752	0.814	0.898	0.992	1.095	1.209	1.335	1.474
ELMA	0.516	0.558	0.616	0.681	0.751	0.830	0.916	1.011
LANCSTER	0.609	0.659	0.727	0.803	0.887	0.979	1.081	1.193
CLARENCE	0.365	0.395	0.436	0.481	0.531	0.587	0.648	0.715
NEWSTEAD	0.455	0.493	0.544	0.601	0.663	0.732	0.808	0.892
ALDEN	0.392	0.424	0.468	0.517	0.571	0.630	0.696	0.768
HOLLAND	0.411	0.445	0.491	0.542	0.598	0.661	0.729	0.805
MARILLA	0.453	0.490	0.541	0.597	0.659	0.728	0.804	0.887
WALES	0.417	0.451	0.498	0.550	0.607	0.670	0.740	0.817
COLDEN	0.381	0.413	0.455	0.503	0.555	0.613	0.677	0.747
SARDINIA	0.436	0.472	0.521	0.576	0.636	0.702	0.775	0.855
BOSTON	0.414	0.449	0.495	0.547	0.604	0.667	0.736	0.813
EDEN	0.338	0.366	0.404	0.446	0.493	0.544	0.601	0.663
EVANS	0.786	0.850	0.939	1.037	1.145	1.264	1.395	1.540
BRANT	0.533	0.577	0.637	0.704	0.777	0.858	0.947	1.045
N COLLNS	0.297	0.321	0.354	0.391	0.432	0.477	0.527	0.581
CONCORD	0.419	0.453	0.501	0.553	0.610	0.674	0.744	0.821
COLLINS	0.369	0.399	0.441	0.487	0.537	0.593	0.655	0.723
IND RESV	0.283	0.307	0.339	0.374	0.413	0.456	0.503	0.555

Table B.11
ANNUAL TONS OF REFUSE PER SQUARE MILE
CENSUS TRACTS IN ERIE COUNTY OUTSIDE BUFFALO

		1966	1970	1975	1980	1985	1990	1995	2000
GRI	73A	130	156	206	281	361	426	491	565
	73B	207	248	329	448	575	679	783	900
CTN	74	863	936	1058	1194	1318	1455	1606	1775
	75	4373	4747	5360	6047	6678	7373	8143	8991
	76	3771	4092	4620	5214	5758	6358	7019	7750
	77	4872	5286	5971	6737	7439	8214	9069	10013
	78	2864	3107	3509	3960	4372	4828	5330	5885
TTN	79A	2556	2825	3230	3689	4073	4497	4965	5482
	79B	3857	4263	4875	5568	6148	6788	7494	8274
	80A	4135	4570	5226	5969	6590	7277	8033	8870
	80B	4974	5497	6285	7179	7927	8752	9662	10668
	81A	2936	3244	3710	4237	4679	5165	5703	6297
	81B	3922	4334	4957	5661	6250	6901	7620	8413
	82A	1662	1837	2100	2400	2649	2925	3230	3565
	82B	4366	4825	5518	6303	6958	7683	8483	9366
	83	613	678	775	886	978	1080	1192	1316
	84	449	496	568	649	716	791	873	964
	85	5006	5531	6328	7225	7978	8809	9725	10737
	86	6634	7331	8384	9575	10572	11672	12888	14229
	87	10150	11215	12825	14650	16171	17856	19715	21768
	88	7643	8446	9659	11031	12178	13446	14846	16393
AMH	89	2761	3361	4295	5525	7015	8251	9544	10948
	90	186	226	290	373	473	557	644	739
	91A	113	138	177	227	289	340	393	451
	91B	290	353	452	581	738	868	1004	1152
	91C	797	971	1241	1596	2026	2383	2757	3162
	91D	899	1094	1399	1799	2284	2687	3108	3565
	92	932	1135	1451	1866	2369	2787	3223	3697
	93A	9891	12040	15386	19789	25127	29554	34183	39210
	93B	2598	3163	4041	5198	6601	7764	8981	10301
	94A	3144	3827	4890	6290	7987	9394	10865	12464
	94B	1931	2350	3004	3863	4906	5770	6674	7656
	95A	2887	3515	4490	5777	7335	8626	9978	11446
	95B	2770	3372	4309	5542	7037	8277	9573	10981
	96	456	555	709	912	1159	1363	1576	1808
CHK	97	2452	2969	3700	4485	5128	5740	6425	7140
	98	667	808	1006	1220	1395	1562	1748	1943
	99	3650	4420	5507	6675	7634	8544	9562	10628
	100A	862	1044	1300	1576	1803	2018	2258	2510
	100B	2900	3511	4374	5302	6063	6787	7595	8442

Table B.11 (Cont.)

ANNUAL TONS OF REFUSE PER SQUARE MILE
CENSUS TRACTS IN ERIE COUNTY OUTSIDE BUFFALO (CONT.)

	1966	1970	1975	1980	1985	1990	1995	2000
101A	4211	5100	6352	7701	8807	9858	11032	12262
101B	3352	4059	5056	6130	7010	7846	8781	9760
102	2722	3297	4107	4980	5694	6373	7132	7928
103	2241	2712	3379	4097	4687	5246	5869	6525
104	9256	11206	13962	16925	19356	21668	24250	26950
105	2591	3137	3908	4738	5418	6066	6788	7545
106	3893	4714	5872	7121	8142	9114	10200	11336
107	997	1207	1504	1823	2085	2333	2611	2903
108	416	504	628	762	871	975	1092	1213
109	1375	1665	2074	2515	2876	3219	3602	4004
110	3315	4015	5002	6064	6933	7761	8684	9653
111	4080	4942	6157	7466	8538	9554	10695	11885
WSN 112	399	477	659	946	1125	1287	1453	1623
113	995	1192	1645	2361	2807	3211	3626	4048
114	4987	5970	8241	11829	14064	16083	18167	20283
115	996	1193	1646	2364	2811	3215	3631	4054
116	1625	1947	2687	3858	4586	5245	5924	6614
117	1822	2182	3011	4322	5139	5877	6638	7411
118	1127	1350	1863	2674	3180	3637	4107	4586
119	745	892	1231	1768	2102	2404	2715	3031
120A	1171	1402	1935	2778	3303	3777	4266	4763
120B	971	1162	1604	2303	2738	3131	3537	3949
LKA 121	2118	2315	2618	2970	3363	3797	4259	4775
122	1109	1212	1370	1554	1760	1987	2228	2498
123	4206	4597	5197	5893	6679	7538	8453	9477
124	2813	3075	3478	3943	4468	5043	5655	6340
125	2720	2974	3363	3813	4320	4876	5468	6130
126	1020	1115	1261	1430	1621	1829	2052	2300
127	2475	2700	3050	3450	3925	4425	4975	5575
HAM 128	1624	1976	2617	3493	4468	5285	6160	7051
129	467	568	752	1004	1284	1520	1771	2028
130	331	402	533	712	910	1077	1255	1437
131	501	609	807	1077	1377	1630	1899	2174
132	156	189	251	335	429	507	591	677
133	2653	3226	4275	5703	7296	8632	10058	11516
134	1517	1846	2446	3263	4174	4937	5754	6587
CPK 135	138	172	231	317	395	474	551	639
136	1532	1903	2563	3509	4374	5243	6094	7064
137	360	447	602	824	1028	1232	1432	1660
AUR 138	157	183	236	305	378	471	551	619

Table B.11 (Cont.)

ANNUAL TONS OF REFUSE PER SQUARE MILE
CENSUS TRACTS IN ERIE COUNTY OUTSIDE BUFFALO (CONT.)

	1966	1970	1975	1980	1985	1990	1995	2000
139	1957	2321	2990	3867	4791	5979	6982	7850
140	1979	2300	2962	3832	4746	5925	6918	7778
ELM 141A	115	137	189	259	322	387	449	521
141B	159	189	261	358	447	535	622	722
LAN 142A	154	189	250	331	403	496	585	671
142B	155	190	250	332	404	497	586	673
143	3696	4533	5976	7918	9652	11864	13987	16056
144	2426	2975	3922	5196	6335	7786	9180	10537
145	2544	3120	4113	5450	6644	8166	9627	11051
CLA 146A	482	568	746	936	1157	1391	1637	1891
146B	129	152	200	251	310	373	439	507
147	70	83	109	137	170	204	240	277
NEW 148	54	67	85	105	128	154	181	209
ALD 149	106	128	162	209	260	315	369	421
HOL 150	30	37	55	75	94	113	135	156
MAR 150	47	53	66	86	105	127	151	177
WAL 150	30	37	53	68	84	100	117	136
CON 151	27	34	49	62	77	91	107	124
SAR 151	19	23	27	33	42	49	57	67
BOS 152	72	94	134	183	224	272	323	375
EDN 153	62	73	92	117	148	175	207	241
EVS 154	219	253	319	419	535	631	742	852
155	269	311	393	515	658	776	912	1047
BRA 156	52	66	86	108	131	158	190	221
NCL 157	27	33	42	54	66	79	92	107
CON 158	18	22	28	36	45	54	64	75
159	503	609	764	974	1198	1447	1711	1999
COL 160	32	38	46	57	71	88	106	125
161	1288	1508	1822	2271	2842	3507	4222	4950
IND 162	29	33	33	27	24	21	20	20

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C.1 Overview of Current Solid Waste Handling Operations

The main characterizations of the solid waste systems and practices within the Buffalo SMSA are independence of operation and minimal coordination among the municipalities and with the private disposal services. Operating under the principal of home rule, each city, town and to some degree, village, within the two Counties has examined its solid waste handling problems and developed its own course of action. The spectrum of selected courses of action range from total municipally-owned and operated collection, processing and disposal functions to municipalities which provide only an open dump. In those instances where the municipality owns and operates the solid waste handling system, the services provided are restricted to residences and to small commercial establishments. Even within the former category, the types and/or amounts of solid waste collected per residence per pick-up is restricted. There are no instances within the Buffalo SMSA of a municipally operated solid waste system which provides all the handling services to all the sources of solid waste generation within its jurisdiction. In general, the forms of solid waste handling within the two Counties can be outlined as

- Municipally-owned and operated collection, processing and disposal with supplementation by private collection and disposal services.

- Municipally-contracted solid waste collection and disposal for residential and light commercial generation of refuse; large commercial and industrial sources privately contracted for solid waste handling services.

- Individually-contracted solid waste collection and disposal with private operators.

- Municipally-operated dump with generation sources transporting their own refuse.

- Privately-operated dump with generation sources transporting their own refuse.

An examination made of the refuse disposal services provided in Erie County revealed that only in the more densely populated portions of the County and a number of villages outside these areas are services provided on an "organized basis". Included in this category of service are the three cities of the County -- Buffalo, Lackawanna and Tonawanda; the towns of Aurora, Cheektowaga, Lackawanna and Tonawanda; and the villages of Alden, Angola, Blasdell, Depew, Farnham, Gowanda, Hamburg, Kenmore, Lancaster, North Collins, Sloan, Springville and Williamsville (see Fig. C-1). It was further established that the towns of Amherst, Hamburg and Lancaster, plus the villages of Akron and Orchard Park were areas currently in need of organized refuse disposal. By the year 2000 with the projected population increases, other towns within the County must provide solutions for their refuse disposal needs. This examination of needs utilized population density* as the primary measure for establishing the adequacy of refuse disposal services.

Within Niagara County the three cities of Lockport, Niagara Falls and North Tonawanda provide refuse disposal services for all residential and a limited number of small commercial establishments. With respect to the remainder of the County, a substantial portion of the village and township residences and commercial establishments are served by private refuse haulers either by direct contract with the individuals served or by contract with the village or township.

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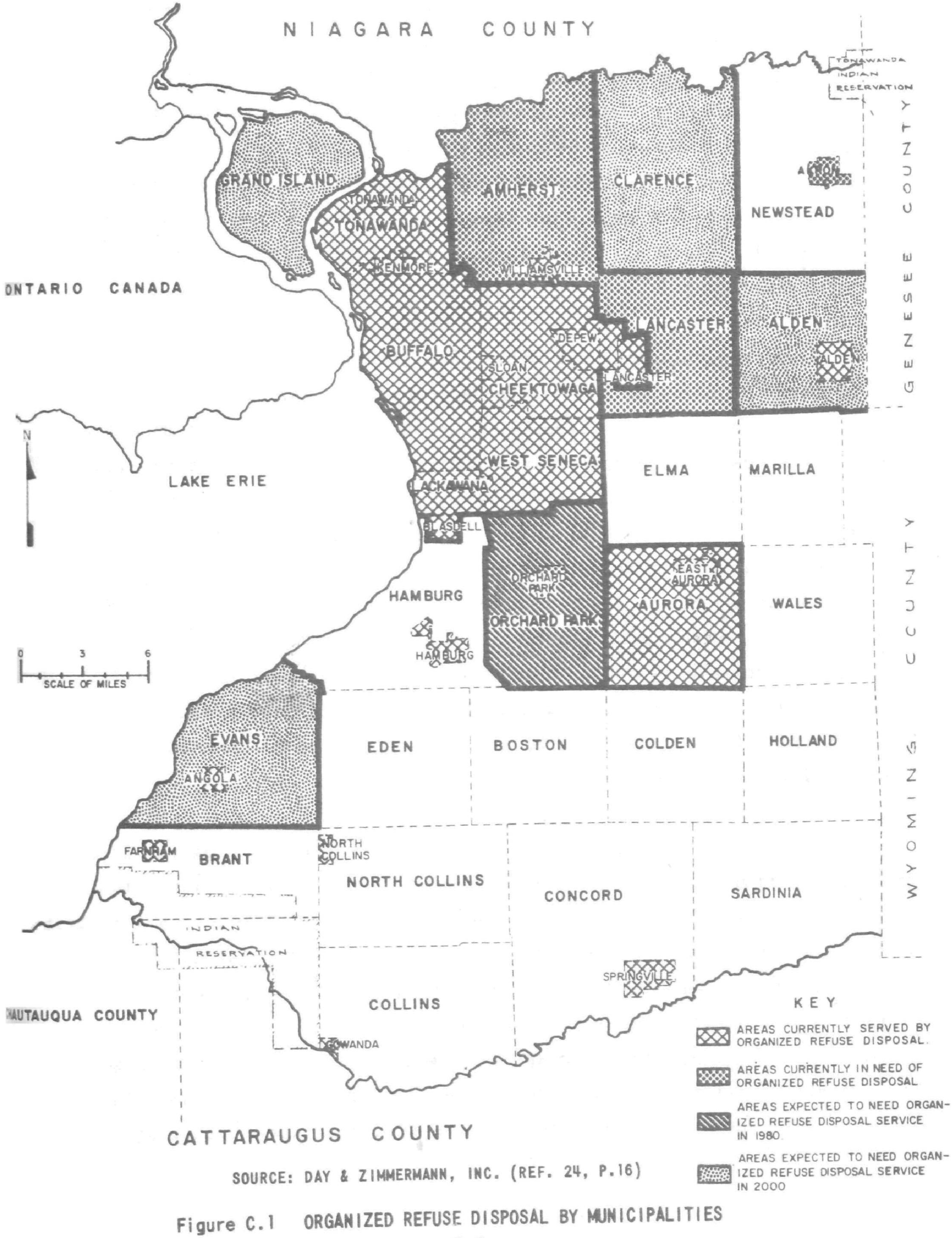
* A rule-of-thumb given in Ref. 36 was interpreted as follows. A government controlled refuse disposal source is desirable when the population density exceeds 1000 persons per square mile. For densities between 500 and 1000 persons per square mile, an organized service should be planned under the conditions of concentrations of one family per acre being prevalent to a considerable degree. For densities below 500 persons per square mile, an organized service is not considered necessary.



SOURCE: DAY & ZIMMERMANN, INC. (REF. 24, P.16)

Figure C.1 ORGANIZED REFUSE DISPOSAL BY MUNICIPALITIES

C.2 Current Solid Waste Handling Practices

A description and synthesis of solid waste handling should begin with the collection function and then proceed to the subsequent stage of the system; be it processing or disposal. From the viewpoint of the recipient of the solid waste handling service the collection function is of greatest interest and concern for several significant reasons. Of primary importance, the generator of solid waste has the responsibility of storing the refuse from the time of generation until it is collected and transported from his location. During this storage period, and depending on the environmental factors, (e.g. temperature, precipitation) and storage facilities, he may be subjected to such effects or concerns as unsightliness, odors, flies, vermin, dust, etc., all of which may be very objectionable. Secondly, from a direct monetary viewpoint, the cost of the collection function relative to the total cost of solid waste handling ranges from between two-thirds and three-quarters of the total cost. For example, in Ref. 2 it is noted that the collection cost per ton is approximately $10 as compared to a total refuse handling cost of $14.75 per ton. On the assumption that the per capita solid waste generation rate is 4.5 lbs. per day at present and the family unit consists of four persons, it is not unreasonable to assign a cost of roughly $30 per annum to the family unit for the collection function alone. In essence these two factors, storage and associated effects, and cost, are the recipients' main concern and interest in the solid waste problem.

Within the Buffalo SMSA, and as evidenced by the planning studies performed for each County, the planning organizations have concluded that the bases for regionalization would be the processing and/or disposal functions, and that the collection function would be performed on a local option basis. It should not be inferred that these planners are unaware of the concerns and interests of the generators of solid waste. Rather, it has been decided that because of the (1) current poor disposal practices; (2) scarcity of available land; (3) air pollution and water pollution resultants of solid waste handling; (4) fund limitations of small municipalities and; (5) economies of scale experienced through cooperation and regionalization, the disposal function should be given the highest priority and secondly the processing functions. In keeping with this priority ordering, which it should be added appears to be in general agreement with other regional approaches to solid waste handling, the descriptions of Erie and Niagara Counties' current solid waste handling practices are organized into the two main functional categories - disposal and processing.

C.2.1 Erie County - Inventory of Disposal Sites and Processing Plants

C.2.1.1 Erie County Disposal Sites

The following description of the Erie County disposal sites is a summary of the information provided in the Day and Zimmermann refuse disposal report for Erie County (Ref.24).

A total of 31 operating disposal sites (landfills) are located in Erie County of which four are situated within the City of Buffalo. Of the 31 landfills, only two were found to meet all the requirements of acceptability set forth in the New York State Sanitary Code Part 19 - Refuse Disposal. Seven of the sites were considered acceptable except for minor regulation infractions. Of the remaining 22 disposal sites, 12 indicate evidence of attempts being made to be operated as sanitary landfills and the remaining ten were generally operated as open dumps. This last group was found to have inadequate land or lack of control of insects, rodents and fires. Fig.C.2 depicts the location of existing refuse disposal sites and the numbers to the upper right of the circles indicate the results of an evaluation of the land fills. The number 1 signifies a landfill fulfilling the requirements of the State Sanitary Code; as the condition of the operation of the landfill deteriorates, the associated health rating number increases. The number 4 specifies an open dump; that is, open uncontrolled dumping and burning.

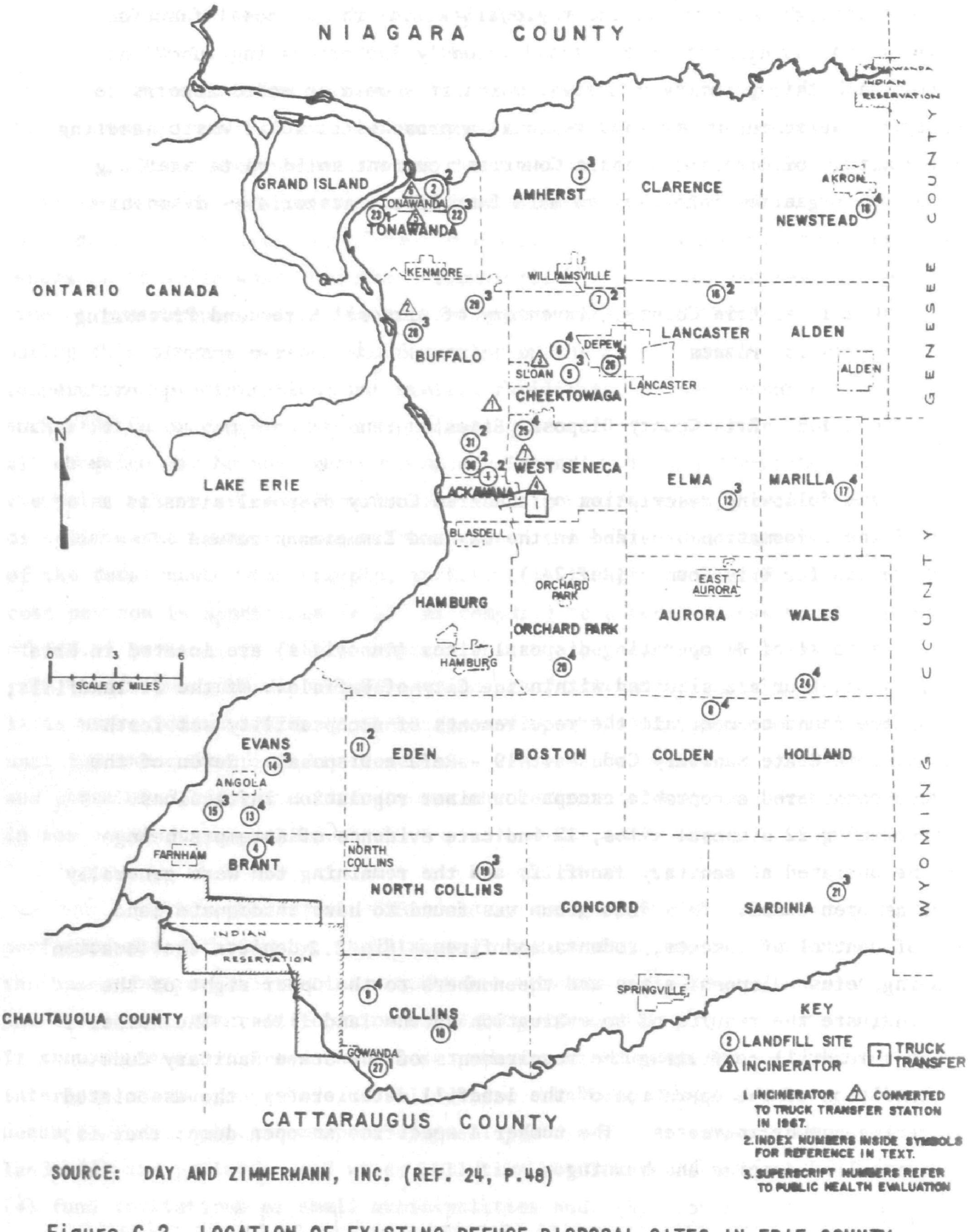


Figure C.2 LOCATION OF EXISTING REFUSE DISPOSAL SITES IN ERIE COUNTY

The landfills, described in Table C.1 , represent a spectrum of nership and operation. As shown in the table, ownership is both public ity, town and village) and private with no strong relationship discernible tween types of ownership and quality of operation. However it can be seen at the town operated disposal sites are rated (on the average) between 3 d 4, the city operated sites are rated between 2 and 3, and the privately-erated sites are rated between 2 and 3.

Within the above survey, it was found that there is a significant ifference in the operating costs of large versus small disposal sites. mination of the operating cost information reveals that the costs associated ith small disposal sites (25,000 cu. yards per year or less) would be of the order f 50 cents to over $1.00 per cubic yard, whereas the larger operation disposal ites have operating costs in the order of 30¢ per cubic yard. In part it s the high unit operating cost of small disposal sites that causes these site erators to seek money-saving shortcuts which result in poor operations and eir poor public health rating.

A tabulation of the space currently available on the disposal sites isted in Table C.1 reveals that there is approximately 20 million cubic yards f available capacity. Using a refuse compactability ratio of approximately 3:1, the current landfills are capable of receiving approximately 50 million bic yards of refuse as collected. Based on an estimated landfill capacity quirement per year of three million cubic yards, the total landfill capacity f the present disposal sites would be completely exhausted in 17 years. Since is estimate does not take into account the availability of specific disposal ites to the various sources of solid waste generation in terms of distance r the willingness of municipalities to share the available capacity, the -year estimate is a very optimistic. In fact, the situation confronting many munities at present is quite critical.

C.2.1.2 Erie County Processing Plants

In Erie County the processing of solid waste is performed primarily

Table C.1 ERIE COUNTY DISPOSAL SITES

Number	Name	Location	Operator	Remaining Life (years)	Rating
1	City of Lackawanna	Lackawanna	City	20	2
2	City of Tonawanda	Tonawanda	City	40	2
3	Town of Amherst	Amherst	Town	2	3
4	Town of Brant	Brant	Town	40	4
5	Town of Cheektowaga	Cheektowaga	Town	1	3
6	NYS Highway Dept.	Cheektowaga	NYS	?	4
7	Pfohl Bros	Cheektowaga	Private	1	2
8	Joe Ball	Colden	Private	?	4
9	Town of Collins	Collins	Town	40	4
10	Collins Center	Collins	Town	?	4
11	Eden Sanitation Service	Eden	Private	15	2
12	Town of Elma	Elma	Town	?	3
13	Town of Evans	Evans	Town	?	4
14	Fox and Vassals	Evans	Private	?	3
15	Ed Ball	Evans	Private	?	3
16	Lancaster Sanitary Landfill Inc.	Lancaster	Private	9	2
17	Tankesley	Marilla	Private	40	3
18	Town of Newstead	Newstead	Town	?	4
19	Town of North Collins	North Collins	Town	40	3
20	Butenkinst Site	Orchard Park	Private	40	4
21	Hugh Smith Landfill	Sardinia	Private	25	3
22	Town of Tonawanda	Tonawanda	Town	2	3
23	Seaway Industrial Development Corp.	Tonawanda	Private	15	1
24	Town of Wales	Wales	Town	?	4
25	Town of W. Seneca	W. Seneca	Town	?	4
26	Village of Depew	Depew	Village	2	3
27	Village of Gowanda	Gowanda	Village	[long life]	1
28	Squaw Island	Buffalo	City	35	3
29	LaSalle Quarry	Buffalo	City	1-3	3
30	South Park	Buffalo	City	?	2
31	Tifft Street	Buffalo	Private	[very long life]	2

by incineration. Currently there are six municipal incinerators which serve the cities of Buffalo (two facilities), Lackawanna and Tonawanda, the towns of Tonawanda and Cheektowaga. With the exception of Buffalo's East Side Incinerator all the furnaces within these six facilities have been installed since 1945 with the most recent one being installed in 1959.

All the incinerators in Erie County are natural draft plants and thus it would be impossible to introduce air pollution control devices to the furnace outlets without installing induced draft fans to overcome the pressure drop. At preset none of the facilities has air pollution control devices adequate to meet the current County Health Department standards. Extensive modifications are well underway at the Buffalo West Side Plant including air pollution control devices which it is claimed will permit this facility to operate within the County's air pollution standards.

A summary of the incinerator operations is included in Table C.2. This table includes some of the pertinent furnace design information, the operating data and appropriate cost data associated with each facility. Also included in this table is the information on the West Seneca facility which was initially operated as an incinerator and since early in 1968 has begun operations as a truck transfer station. It should be noted that the one-way disposal haul distance from the West Seneca transfer station to the Disposal Site (Site #16 - Lancaster Sanitary Landfill) is approximately 15 miles.

C.2.2 Niagara County - Inventory of Disposal Sites and Processing Plants

C.2.2.1 Niagara County Disposal Sites

The disposal sites in Niagara County can be broadly categorized as publically-owned and lease-operated sanitary landfills, open burning dumps, modified sanitary landfills, and burning dumps and landfills, and industrially owned and operated landfills. The Cities of Niagara Falls, North Tonawanda and Lockport, and the towns of Hartland, Lewiston, Lockport, Newfane, Niagara, Royalton, Wheatfield and Wilson operate on-lease disposal sites.

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Table C.3 summarizes disposal site information which is derived from A. Michael's Refuse Disposal Report (Ref. 22). Included in the table are the name of the political subdivision, the type of disposal site being operated and additional remarks such as expected life of the site, specific pollution problems, etc.

The map of Niagara County (Fig. C-3) provides a reference of the spatial relationships among the towns and cities. The locations of the disposal sites have not been shown since they have not been included within the analyses described in Section 4 of this report.

C.2.2.2 Niagara County Processing Plants

The Cities of Niagara Falls and North Tonawanda both operate incinerators for the processing of residential and light commercial refuse. In 1965, Niagara Falls incinerated approximately 44,400 tons of refuse out of a total amount of 46,000 tons or 96 percent. The City of North Tonawanda disposed of approximately 8000 tons of refuse at its incinerator out of a total surveyed quantity of 20,500 tons, or 39 percent. The amount of incinerated solid waste included some industrial material which was hauled to the plant by private industry.

One note of interest is the comparison of the costs per ton of processing for each incinerator. The Niagara Falls incinerator processed 44,400 tons in 1965 and the average cost per ton was $5.35. The North Tonawanda incinerator, operating at one shift per day, processed 8000 tons in 1965 and the average cost per ton was $8.00. Whereas the cost experience of Niagara Falls was comparable to incinerator experiences in the Northeastern part of the U.S., the higher cost per ton of the North Tonawanda incinerator is a strong indication of the cost inefficiency associated with very small scale operations.

Table C.3 NIAGARA COUNTY DISPOSAL SITES

(as of June 1966)

Name	Type Operation	Remarks
Cities		
Niagara Falls	Modified landfill	Disposal of incinerator residue Virtually filled - being replaced by site with life of 2-5 years
	Open burning dump	Considerable amount of smoke and fly ash
North Tonawanda	Sanitary landfill	< 1 year of fill life
Lockport	Sanitary landfill & open burning dump	30 year fill life
Towns		
Hartland	Modified landfill	Insect and rodent nuisance exists - potential fire hazard
Lewiston	Open burning dump	Attractive to insects and rodents; causes air pollution, and is fire hazard
Lockport	Modified sanitary landfill	Wells in area contaminated by operation
Newfane	Sanitary landfill and open burning dump	Numerous rat harborages
Niagara	Open burning dump	Minimal available space
Royalton	Modified landfills	2 sites - Bancroft site has long history of nuisance violations
Wheatfield	Supposed to operate as sanitary landfill	Complaints of rats and rubbish fires
Wilson	Cut and cover land fill operation	Well operated

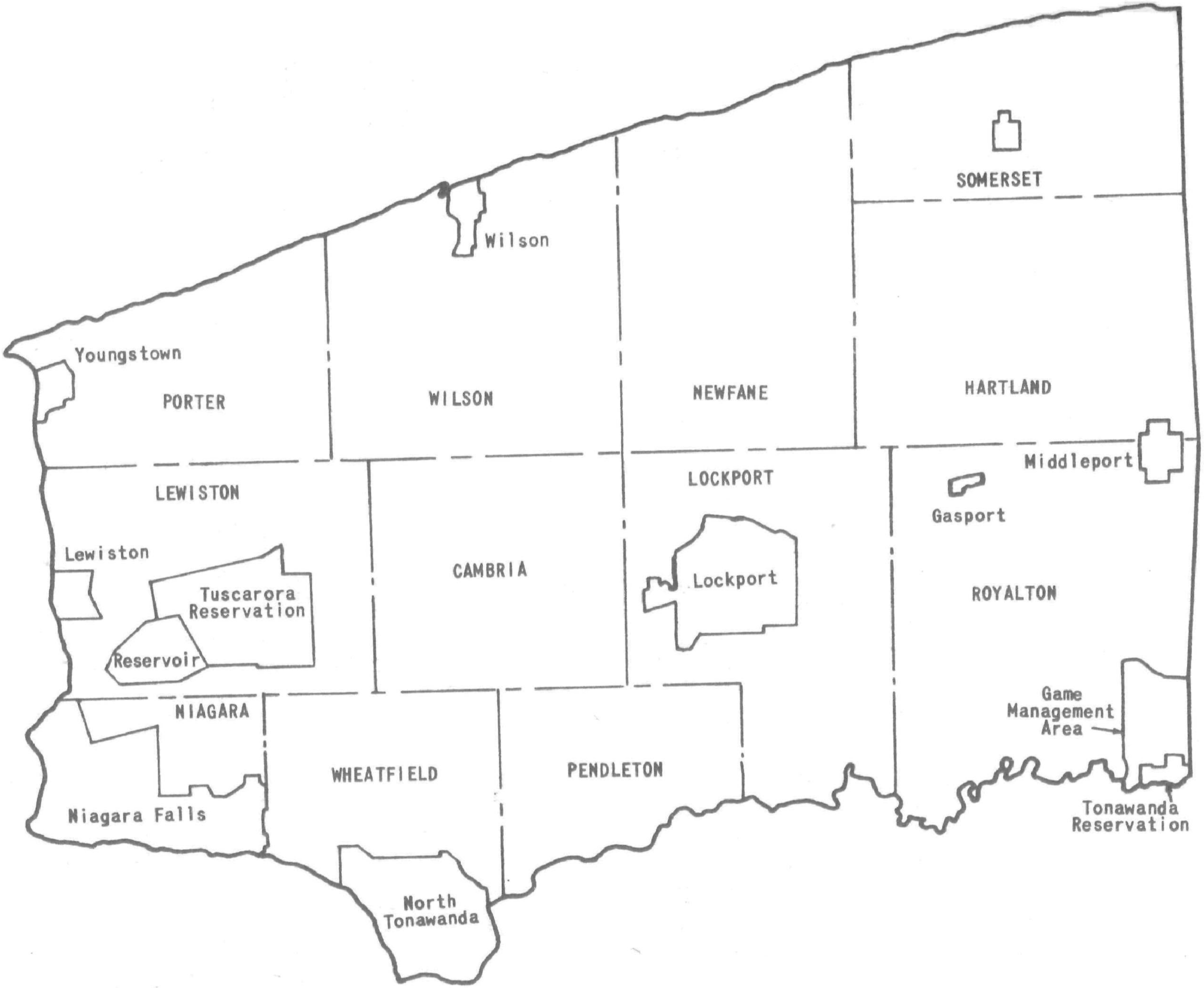

Figure C.3 MAP OF NIAGARA COUNTY

C.3 Comments on Current Solid Waste Handling Practices and Facilities

A general appraisal of current solid waste handling practices and facilities in Erie and Niagara Counties leads to the conclusion that much is required to be done to improve the services to the producers of solid waste, and that the level of operation of facilities require drastic upgrading.

The residential sources of refuse, which are serviced by municipally-operated systems, are provided limited service in terms of the types and quantities of refuse which is collected. The large commercial and industrial producers of solid waste must utilize privately-operated systems which, outside of requiring licenses from the area they service, are not included in any regional planning. Outside of the Erie County Refuse Agency which is primarily an advisory group, and the recently established Niagara County Refuse District, there are no evidences of cooperation and joint planning. Thus, as is indicated earlier, only certain portions of Erie County are covered by organized refuse handling services; this lack of service is more prevalent in Niagara County.

In summarizing the status and operations of disposal sites and processing plants two aspects were prominent. First, on an over-all basis, the majority of these facilities are being operated in a manner which is either aesthetically unsatisfactory, or in need of major improvement to meet health requirements, or both. None of the incinerators in Erie County is currently able to meet the minimum air pollution standards. Many of the landfills are open dumps, with some burning, which serve as breeding areas for insects, and vermin, and as sources of air and water pollution. Second, in view of the small size of many of the landfills, several of the incinerators and the transfer station, the cost per ton of refuse is either higher than that found in the Northeastern part of U.S. or the level of service provided per dollar is lower.

It is quite evident that there is a need for consolidation of solid waste handling services, thereby allowing for greater economies of scale to be realized and to allow for the selection of alternative approaches from a greater spectrum of options which would normally be available to the individual political subdivisions. With respect to the economy of scale factor, an increase of the landfill operation from 100 tons a day to 500 tons a day of refuse handled could result in a cost reduction of approximately one-half, for a similar level of service. As an example of an expanded option spectrum, unless the quantity of refuse handled by a rail transfer station is of the order of 500 tons, it would not prove to be an economic alternative to consider seriously.

Finally, in examining the current disposal site patterns and practices it is clear that an impending shortage of available, accessible land for refuse disposal is being experienced and will develop into a major problem. One contributing factor is the lack of recognition and planning between the private and publically-owned and operated refuse disposal systems. To a large extent they are competing for this scarce resource --land-- and only through a cooperative effort can this scarce commodity be utilized more efficiently -- to the benefit of the producers of solid waste and to the operators of the solid waste systems.

APPENDIX D TECHNOLOGICAL AND MANAGEMENT OPTIONS FOR BUFFALO SMSA SOLID WASTE HANDLING

D.1 Statement of Developing Problems and Associated Solid Waste Handling Requirements

Prior to the discussion of developing problems and the types of requirements which may solve or alleviate these problems it should be mentioned that one of the major difficulties, if not the major one, is defining problems in the absence of a clear, concise statement concerning the objective(s) of solid waste management. Is the objective to move refuse from a generation source where the presence of refuse is objectionable to some other location; to eliminate the health hazards associated with refuse; to collect and dispose of refuse at minimum cost; to maximize the utilization of all resources associated with solid waste handling; to ......; to......; etc. The highlighting of this deficiency or problem is not done for the purpose of beclouding the real-world planning and operating solid waste problems but rather to suggest that unless the objectives of solid waste handling are specified it is difficult to perform management decision-making. To reiterate a concept included in Section 2, the objective(s) selected must be related to the level at which the problem is being examined. That is, utilizing solid waste handling objectives which have been selected at the National-level would, in most instances, be highly irrelevant at the local (village, town) levels. Thus, any attempt at precise problem definitions and system requirements must be coupled to the objectives of the system -- what explicitly is desired to be accomplished?

The growing interest in solid waste handling within the Buffalo SMSA is the recognition that the methods and techniques being employed cannot or should not be maintained at the current levels of performance in order to meet the projected demands. In some instances these approaches are infeasible (not sufficient available land to all municipalities for continued disposal) and in other instances there is an appreciation that there are better ways to provide refuse handling at either the same or reduced cost. Among the most significant factors which are responsible for the developing solid waste handling problems are the following:

(a) Shifting population patterns in Region - As described in Appendix A, the population shifts being experienced are from the urban centers to the rural areas which are taking on many of the attributes of the suburban areas. In most instances the suburban communities which are adjacent to the urban centers have become stabilized in terms of population and thus, based on natural birth and death rates, are experiencing a net out-migration. The impact of this population shift on solid waste is twofold:

(1) The rural communities require an expanded capacity of current services to meet the needs of their rapidly growing populations, and

(2) The population moving into these new areas are demanding a higher level of solid waste handling services than had previously been afforded to the rural inhabitants. Additionally, in some instances some of the solid waste handling practices which had been performed previously are being objected to by these new inhabitants and in some cases have been terminated.

If the previous patterns of local solid waste handling are to continue, land use plans are required which include adequate land reserves for the growing population and which are compatible with the levels of service that the incoming population are demanding. On the presumption that a regionalization scheme will be adopted, planning must be performed to provide an adequate tax base to finance this increased level of service.

(b) Limited available and accessible land - As the population relocates from the densely populated urban areas to the suburban and rural areas of the region, the land utilized per capita increases. The movement of population has the effects of reducing the available lands available for solid waste handling purposes in terms of the actual amount of land being directly utilized by this population and the further requirement for larger buffer zones between the residential areas and the processing plant or disposal site.

With the growth of suburbanization, around the urban centers of the Buffalo SMSA, the problem of accessible land to the high quantity generators of solid waste becomes more acute. In addition to the direct problem of greater transportation costs is the political jurisdictional factor which exists in the region composed of autonomous, locally-operated solid waste handling systems. Municipalities are unwilling to have other municipalities' solid waste disposed of within their jurisdiction unless there is a direct economic benefit to them with virtually no deleterious effects. There are instances where, given the economic gains and the absence of penalties, the local communities are unwilling to cooperate.

The impact of this limited available and accessible land, whether actual or jurisdictional, is to reduce the option spectrum available to local decision makers. On a regional-basis, with the opportunities of large-scale operations, the problem of land availability is reduced and the determination of accessible land is modified because of the opportunities to achieve economies of scale which then enlarges the accessible land region.

(c) Improved level of operation standards - Over the past five or more years, the New York State Health Department and the County Health Departments have promoted legislation to both improve the standards of operation of solid waste handling systems and to increase their abilities to monitor and enforce conformance to these improved standards of operation. These standards are related to air pollution, with respect to particulate matter emission, constituent gases such as sulfur dioxide, oxides of nitrogen, hydrocarbons; vermin and insect control; ground water contamination; as well as odors and aesthetic consideration.

The enforcement of these more stringent standards has resulted in the termination of operations at certain facilities. (For example, the shutdown of the village dump of Akron, New York, which resulted in the elimination of all village-owned and operated disposal services.) Another impact of these standards on small communities has been the imposition of higher tax levels to finance the modification and improvement of the operating standards to existing facilities. A third effect of these standards is to eliminate certain options for solid waste handling previously available to local communities because of the significant increase in cost required to meet these standards.

In recognition of the implication of these more rigid standards of operation and the prospects of even greater controls, the local communities should be making projections of their solid waste handling requirements and deciding whether the options available to each of them are technically and economically feasible, and then comparing their most suitable options with those available to them through a consolidation of refuse handling services on a regional basis.

D.2 Currently Planned and Considered Technological and Management Options

On a National basis, one current approach to meet the aforementioned problems is the establishment of solid waste handling districts -- a form of regionalization. In Erie County, after several years of study and deliberation, a gross plan has been formulated which, although modest in scope, permits an assessment of cooperative solid waste handling facilities, and meets some of the current problems of participating municipalities. The plan, based on a voluntary concept, would establish one or several truck transfer stations and provide the required transportation capabilities to a county-owned or licensed landfill site. Because of the preliminary nature of the planning effort and the lack of specific and binding commitments on the part of individual villages, towns or cities, the number and locations of the transfer stations have not been established and the selection of the disposal site has not been made. Therefore, at this time, it is not possible to describe the details of the plan, to estimate the cost of implementation (capital and operating costs), and to evaluate the decisions made. The nature of the plan can be described as a demonstration project rather than one whose purpose it is to handle the current problems; to anticipate future difficulties and provide for their orderly solution.

D.2.1 The City of Buffalo Activity

Within the Buffalo SMSA, a number of actions are being taken and are under consideration for alleviating portions of the solid waste handling problem. Before summarizing some of these actions, it should be stated that none of them is being formulated and evaluated from a total system point of view but rather each is being investigated in terms of a specific portion of solid waste handling. There is no attempt to formulate an optimum solid waste handling system.

The City of Buffalo's solid waste represents approximately 45 percent of the total of Erie County and its population is approximately 45 percent of the County. In view of the fact that its area is only four percent of the County total, the City is confronted with a solid waste handling crisis. To meet this crisis, the following actions are being pursued at the present time.

(a) Over the past year and a half, the Buffalo West Side Incinerator Plant has been undergoing a major rehabilitation and expansion, which should be completed sometime in 1969. As part of the expansion, a continuous feed grate furnace of 200 tons per day is being installed as well as a bulky-refuse burner of 60 tons per day. Based on the 1966 daily burning rate of approximately 307 tons per day, the total capacity of the plant will become 567 tons per day; or an expansion of 85 percent. A significant benefit to be derived from the bulky-refuse burner is the processing of currently oversized objects which are disposed of at the landfill with the accompanying penalty in scarce landfill capacity. A significant aspect of the modernization program is the addition of air pollution control equipment to the existing and additional furnaces which, it is predicted, would allow the incinerator to perform in conformance with the new State and County air pollution control regulations.

The second incinerator within the City of Buffalo -- the East Side Incinerator is approximately 40 years old, in need of major overhaul and modernization and not capable of conforming to the current air pollution control standards. The City of Buffalo is considering a number of options to meet this present deficiency. The alternatives being pursued are (a) a new 600 ton per day incinerator which can be expanded to 900 tons per day, and possibly to 1200 tons per day; (b) a 200 ton per day truck transfer station which would be obtained through the conversion of the existing incineration station; (c) a 400 ton per day composting plant; and (d) a 200-600 tons per day sanitary land fill operation. Each of these alternatives would be put out for competitive bidding so as to derive a sounder basis for selecting the type of facilities to be selected. Whereas the expansion of the West Side Incinerator is a project which is well under way and thus rather well defined, the efforts associated with the East Side Incinerator, or more specifically the area within the City serviced by this incinerator, characterize an earlier stage of the planning process.

D.2.2 A Demonstration Within Niagara County

A demonstration project has been undertaken by Niagara County to establish the application and merits of a specialized piece of equipment to be used in sanitary landfill operations. In principle, the machine receives refuse from a collection truck and then proceeds to shear, crush and extrude the refuse from a press into the trench which is being excavated by the trencher wheel. The excavated earth is subsequently replaced in the trench and is compacted. It is estimated that the "D and J Press" Refuse Disposal Machine is capable of performing the above operations within approximately five minutes while handling 15 cubic yards of refuse per cycle.

D.2.3 Town of West Seneca - An Example of Facility Conversion

With the advent of the new Erie County air pollution standards and the rapidly increasing quantity of refuse generated in the Town of West Seneca, the Town decision makers were faced with the options of either modernizing and enlarging their 60 tons per day rated capacity incinerator or select some other alternative for solid waste processing. It was decided to construct a truck transfer station for a variety of reasons among which were: (a) the minimization of air pollution problems associated with a well-operated transfer station, and (b) the many characteristics and facilities of the existing incinerator plant lend themselves to relatively simple modification and economic conversion for re-use as a transfer station. The transport equipment for hauling refuse from the transfer station to the landfill site consists of two 70-75 cubic yard capacity trailers and one tractor. Based on three to four round trips per tractor trailer per day, the refuse disposal capacity of the system is approximately 240 cubic yards. The addition of a second tractor will increase the refuse handling capacity to about 480 cubic yards per day.

It is planned that future increased capacity can be obtained by the installation of an additional hoppers, stationary ram packer units, and transfer-trailer stalls.

Based on a capacity estimate of 60 tons per day and a landfill disposal charge of 30 cents per cubic yard, it is estimated that the total cost (including direct labor, maintenance, supplies, fuel and utilities, landfill charges and amortization) is $4.90 per ton. For a 100 ton per day operation, the total cost is $3.90 per ton. Although these charges are fairly high for truck transfer operations, they are heavily dependent on the limited size of the operation.

D.2.4 Carborundum Company Uni-Melt. A Technological Innovation being Examined

In recognition of such problems as (1) air pollution, (2) the relatively large volume of residue (15-20%) from conventional incineration, and (3) the low temperatures of conventional incinerators which thus require that many types of refuse be sent directly to disposal sites and thereby inefficiently utilize this scarce resource, the Carborundum Company has developed a processing concept called Uni-Melt. Basically, the Uni-Melt concept is built around the pyrolysis process which is conducted in the neighborhood of 3000°F. At this temperature, the processing facility is capable of handling virtually all types of solid waste and it is estimated that the resulting inert residue should be approximately 5 percent by volume of the solid waste charged. The principal components of the Uni-Melt consists of a (a) hot blast heater which furnishes preheated air at temperatures in the vicinity of 1800-2000°F; (b) a gasifier into which the refuse is charged and is then volatilized; (c) an igniter within which the incomplete products of combustion are completely combusted; (d) and (e) spray tower and bag filter to reduce and virtually eliminate any particulate matter. The residue obtained from the Uni-Melt process is a slag-like substance which may have application in the construction industry as well as a road construction material. Because of the high temperatures maintained in the gasifier, it can be expected that the residue will be quite uniform and thus require no preheating before it is utilized.

Since no pilot plant has been constructed and operated, it is not possible at this time to assess the technical and/or operating problems which may be encountered. A demonstration project is being contemplated which includes the construction and operation of a Uni-Melt facility having a capacity of 75 tons per day. If the process proves technically and economically feasible and reliable, and if, as recommended, the facility is located near the town lines of Boston, Concord and North Collins in Erie County, it should be capable of meeting the total refuse processing needs of this portion of the region.

D.3 Feasible Technological and Management Options

With the rapidly growing concern with the solid waste handling problems throughout the world, very considerable amounts of research and development efforts are being expended in the areas of collection, processing and disposal. To a degree, the applicability of the research and innovations is dependent on such local factors as the types and amount of waste being generated, the availability and cost of land and labor, the attitudes and legislative restrictions imposed on solid waste managers, and the financial capabilities of the region to acquire and operate the specific facilities.

No attempt will be made to enumerate and describe all the various research approaches and innovations which are being investigated; only a sampling of these efforts is described below. Furthermore the sampling incorporates some processes which have been utilized successfully in other parts of the United States and/or in other countries, but not in the Buffalo SMSA. For example, the inclusion of a vacuum refuse system within the collection category is made with recognition of its employment in Sundeberg, Sweden. A second example is the inclusion of the Tezuka-Kasan "garbage block" system within the processing category. This system could also be viewed as a value-adding waste handling process. Thus, the options included are those which have not been seriously considered by the refuse managers in the Buffalo SMSA and are illustrative of the broader spectrum of choices which are available for meeting some aspects of the regionalized refuse problem.

Since the collection function constitutes roughly two-thirds to three-quarters of the cost of solid waste handling, a considerable amount of effort is being expended in this area and to reduce the quantity or volume of refuse being collected. In general the "advances" have been rather straightforward in concept; that is, attempting to apply existing technology in a more economic manner. Prime examples of these efforts are train-type collection vehicles, various forms of on-site compaction units and improved on-site incinerators. Two examples of significant innovations related to collection and transport are:

(a) Sweden's vacuum collection system which is a pneumatic refuse transportation system, and

(b) Zandi's hydraulic collection system which is a collection-transportation system within which solid waste is transformed into a slurry and transported within water carrying pipes (this research is being supported by the Solid Wastes Program)

(c) Conveyor systems for collection and transport of solid wastes to one of several destinations e.g. a centralized collection pickup point; to a processing plant; directly to the final disposal site.

Each of the above developments reduces the manpower requirement, and eliminates the amount of moving vehicle needs (with their associated deleterious effects) but entails large capital expenditures.

The second largest cost component in solid waste handling is related to the processing function. Beyond the direct costs associated with such processing alternatives as incineration and composting are the indirect social costs which if significantly reduced would increase the direct cost of processing. In general most of the research and development in the area of processing can be categorized in the following manner: (Ref. 11).

(a) Chemical Oxidation Combustion
- Central Municipal Incineration
- Centralized Incineration
- Wet Air Oxidation
- Pyrolysis, Distillation and Other Oxidation Processes

(b) Biochemical Oxidation
- Composting
- Anaerobic Processes

(c) Physical Size Reduction
- Commercial, Institutional, and Industrial Grinders
- Central Garbage Grinding Stations
- Central Pulverization Plants
- Compaction
- Pulping
- Dewatering

(d) Salvaging - Reclamation - Reuse - Physical Separation

In general, category (a) Chemical Oxidation Combustion has been viewed primarily as a means of achieving volume reduction and rendering the solid waste chemically inert. With the fairly recent development of high temperature incineration (Melt-Zit process of the American Development Design Corp.) and the pyrolysis process (Uni-Melt of the Carborundum Company), the residue resulting from these processes are being considered as commercially-useful materials thereby eliminating much of the need for subsequent disposal of the process residue. A similar point of view has been held relative to category (c) Physical Size Reductions, that is processing the solid waste so as to alleviate the requirements for subsequent solid waste disposal operations. The very high pressure compaction (Tezuka-Kasan)process of solid waste and the cladding of refuse block with either concrete or iron results in a product which may have considerable commercial value for such purposes as bulkhead, retainer wall and foundation construction.

Categories (b) Biochemical Oxidation and (d) Salvaging - Reclamation - Reuse - Physical Separation have traditionally been thought of as value-adding processes. Unless value-adding can be viewed from an over-all national resources conservation position, they have not in the recent past proven to be of significant and continuous economic benefit as a method of processing the solid waste of a municipality or region. In specialized instances, such as the salvaging of paper and rags, from industrial waste or because of special locational factors (the shipping of tin cans from Chicago to the Copper smelters in the Southwest) there have been some successful operations.

Developments directly associated with the disposal function have been rather traditional which may be explained partially by the facts that this function is the least costly of the three major solid waste handling functions and the greater emphasis on various processing and associated transport operations which directly affect disposal. But as has been repeatedly stressed throughout this report, much of the National interest and urban concern relative to solid waste stems from the limitation of accessible and available land needed for the disposal function.

Beyond the broadening of perspectives of accessible disposal sites which involves the development of most cost-effective transport systems, most of the disposal entails open dumping on land, and a variety of sanitary landfill operations. Furthermore as a means of deriving "greater" capacity from disposal sites, obtaining greater public acceptance and enhancing the utility of the sites being utilized, more comprehensive planning is being given to the ultimate uses of the completed site. For example, as a means of increasing the capacity of the site and obtaining public acceptance such end-uses as coaster hills and ski slopes are being developed from the disposal operation.

Thus as mentioned earlier, the number of technological options available to the regional solid waste planner are fairly extensive. The major factors limiting the scope of the options available to a specific region are (i) the vision and willingness of the planners to try something different; (ii) the ability of the region to support the associated costs of the operations and facilities; and (iii) finally, the solid waste operating standards which are being demanded by the population.

In addition to the aforementioned technological options available to the region, another spectrum of options which can provide a major assist to solving the regional problems is the application of sound management practices. Whereas some urban areas of the United States, notably Los Angeles and New York, have recognized the benefits of applying scientific management techniques and management information systems to solid waste handling operations and planning, the majority of the Country has for a variety of reasons not availed themselves of this capability. In part, this is a function of the cost of acquiring and maintaining the capability, the limitations of the people currently operating and planning solid waste systems, and the fairly low status that solid waste handling has in local governmental organizations.

As illustrative of the contributions that can be derived from the application of management science techniques two examples are offered - the first relative to operations and the second relative to planning. Within an urban area, there are continuous shifts in land-use patterns and population densities which thus influence the types and amounts of solid waste being produced. Since little or none of these movements are explicitly known or fully appreciated by the solid waste manager (usually the Commissioner of Sanitation and his staff) the utilization and scheduling of men and collection equipment are not modified accordingly. It is apparent that the operations could be improved significantly if the scheduling were done on a dynamic-basis based on the availability of current and projected data which could be stored and processed within a solid waste management information system. Such improvements as greater productivity per man-hour or equipment-hour within the collection function (the most expensive portion of solid waste handling); reduction in waiting times of vehicles at processing plants and disposal sites; improved reliability of equipment through proper maintenance scheduling should be achievable.

Within the area of planning much of this activity is currently performed at a point of impending crisis when the major thrust of the planning is to find solutions to meet the immediate problems and, in passing, to give some rather general considerations to the longer-range problems. This planning also has the characteristic of being "one-shot" efforts in that once a plan is formulated, parts are implemented and the planning activity is then minimized until the next crisis period. The effective application of planning for solid waste is to maintain a continuous information gathering activity concerning changes in types and quantities of refuse, the location of refuse generation (these are similar to the information required for operations), future land-use plans, and technological changes in collection, processing and disposal functions. With information of this nature, plans can be made and actions taken to avoid the crisis-to-crisis mode of planning and to establish a well-conceived integrated and coordinated regional solid waste handling system. The two main activities in this form of planning are continuous information gathering and processing, and the development, review, and assessment of plans for future actions.

These two brief examples are simply illustrative of the variety of applications of sound management science technology to the current and long-range problems of solid waste management.

APPENDIX E CONCEPTUAL SCREEN AND SCREENING PROCEDURE FOR PRELIMINARY ASSESSMENT OF SOLID WASTE OPERATIONS* AND SYSTEMS

E.1 Introduction

In the evaluation and selection of solid waste operations and systems, the decision-makers with the aid of their analysts are confronted with a broad spectrum of alternative choices. As an integral part of the system planning procedure, detailed study of these alternatives is required so as to determine whether the operation or system meets the solid waste handling requirements of the region in such terms as the types, quantities of refuse, costs, physical limitations, etc. Beyond meeting handling requirements, the system should be evaluated relative to various performance standards and associated acceptance levels, as specified by the numerous interests within the region.

Within the context of this Appendix, the term handling requirements of the region refers to those operation or system properties which are related to: (a) the characteristics of the refuse to be processed and/or disposed; (b) the quantity of refuse to be handled; (c) the rate at which the refuse is to be processed and/or disposed; and (d) those properties which are related to the capability of the operation or system to handle the region's refuse within the required reliability and adaptability constraints. The second category of operation or system properties, referred to as standards, are those factors which are associated with the health, aesthetic, environmental, political, land-use variables, and for which performance levels have been specified for or desired by the population of the region. Certain of these standards may be classified as subjective since they reflect, to a high degree, the type of environmental quality that the population specifies and is willing to support financially. In many of these instances, there are no direct monetary trade-offs between the benefits accrued by changing the acceptance level associated with a given standard (e.g. noise level) and

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*An operation is defined as any major stage within the solid waste handling system functions of collection, transportation, processing and disposal.

the cost of achieving this modified level. For these variables, the body politic selects levels (usually through a rather cumbersome and sometimes mysterious procedure) to be met by a solid waste system and thereafter, any acceptable alternative (operation and/or system) is required to perform within these levels. Even in those instances where it is possible to demonstrate the monetary trade-off relationships between the benefit derived by the region for acquiring an operation or system capable of operating at a specified level with respect to a given standard, and the additional operation or system cost to achieve this level, it certainly does not follow that the acceptance level selected by the region is the optimum benefit-cost point. The decision concerning the specified level is based on the criterion established by the regional decision-making bodies (including in some instances the citizens) and the availability and/or willingness to commit the necessary resources.

Fig. E.1 depicts the general relationships of costs and benefits (described in terms of cost) to a region for levels of particulate matter associated with a given operation such as an incinerator. Whereas the minimum total cost (C^*_T) to the region may be achieved by selecting the particulate matter level of L^*, the cost of illness (C^*_I) related to this level of particulate matter (some combination of number of illness and severity of illness) may be objectionably high to the population. Thus, from a health standpoint alone, the region may select particulate matter level L_1 which would significantly reduce C_I but would increase both the cost of procuring the particulate matter abatement measures (C_A) and the total cost (C_T).

The establishment of objective acceptance levels for given standards is exceedingly difficult for at least the following reasons:

(a) The quantitative relationships between the standards, within the domains of health, aesthetics, environment, etc., and objective measurements associated with the standards are extremely difficult to establish. In most cases these relationships are virtually impossible to determine on any statistically significant basis with the current state-of-knowledge.

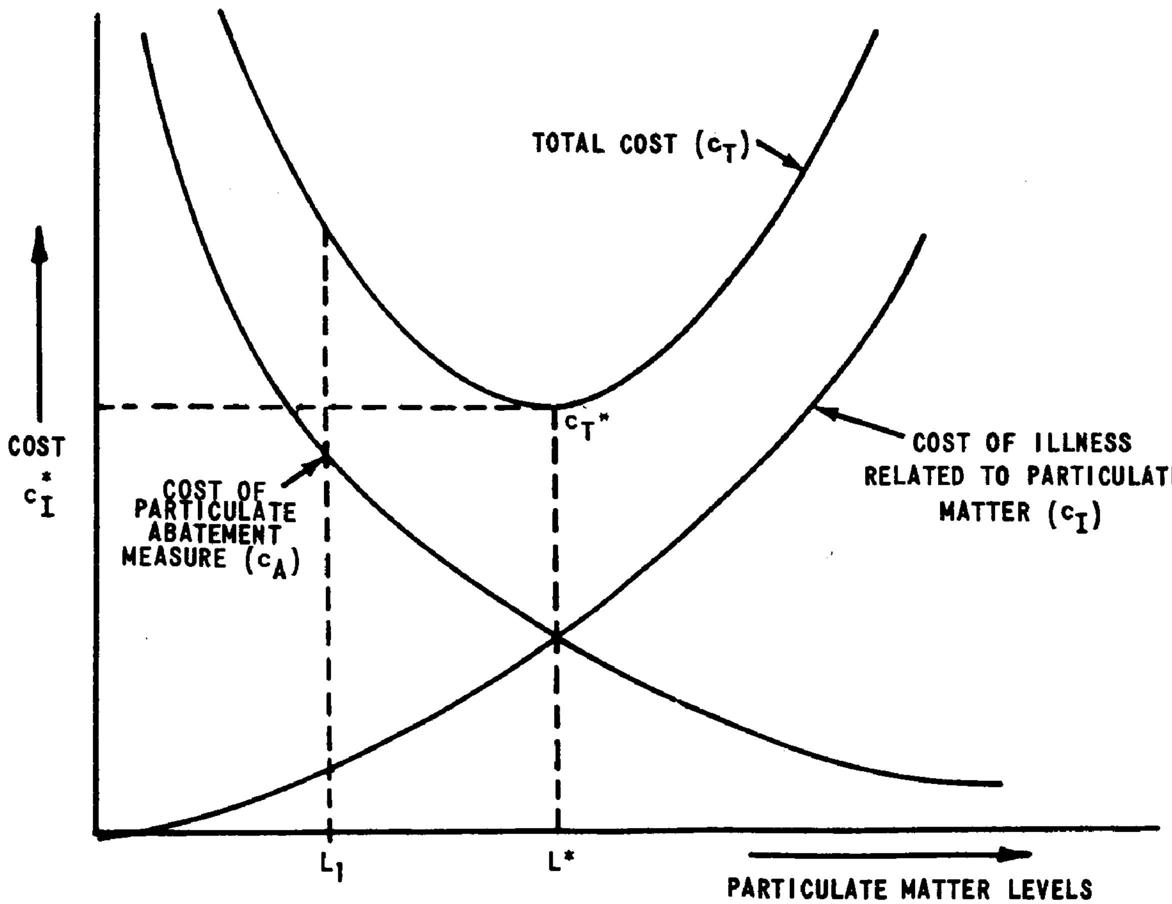

Figure E.1 RELATIONSHIPS OF COSTS AND PARTICULATE MATTER LEVELS

(b) Assuming that the relationships can be established, there remains the problem of describing the dependent variables in some common unit. The unit most commonly utilized is a monetary one since the decision to be made usually requires an expenditure of funds and therefore some "trade-off" between funds expended and monetary benefits derived.

E.2 Formulation of a Screen and Screening Procedure

The effort required for examining and evaluating a candidate solid waste operation or system, or synthesizing systems from screened operations can be reduced considerably if a screening procedure is employed initially. The formulation of a screen, and screening procedure starts with the condition that a set of standards and their associated acceptance levels have been specified. It is assumed that these standards and acceptance levels have been derived based on both an assessment of what is desired and some gross estimation of their implications in terms of the technical opportunities available for achieving the acceptance levels.

The screen and associated screening procedure consists of a series of tests and comparisons of the operation or system to determine whether all the acceptance levels can be met by the candidate being tested. Given that a system passes through the screen successfully, it is now an acceptable candidate for the more extensive evaluation procedure, as outlined within the Regional Solid Waste Handling Evaluation Model described in Section 3. This subsequent evaluation considers the system's refuse processing and/or disposal capabilities, its performance and associated costs over the planning horizon or the system's useful life, whichever is shorter. The evaluation model requires inputs concerning the system's physical characteristics, operational performance, initial and operating costs, material reclamation and salvaging properties (if any) and its impact on other aspects of the regional planning (e.g. the need for roadways or road characteristics).

The remainder of this Appendix is a description of the screen and screening procedure. The description should be viewed as conceptual since the details of the individual screen stages as well as the number of stages requires precise definition, and the screening procedure (including the process or system modification operations) could be made more efficient. For example, whereas the screening process calls for a modification step at each stage within the screen, it may be more efficient to permit the candidate operation or system to be evaluated at all screen stages and only initiate the required modifications after the "screening" has been completed. Additionally, whereas the screen and screening procedure appears to have broad utility, the specific measures and acceptance levels must be specified to meet the objectives and requirements of individual regions.

In essence, the screen consists of a number of individual stages each of which is related directly to a specific standard (S_i) and its associated level of acceptance (L_i). The stages are categorized into three main classes:

(a) Immutable
(b) Conditional
(c) Negotiable

The immutable class includes those standards and levels whose deleterious effects are well understood and, because of externally imposed regulations, no deviations from the acceptable (specified) levels are tolerated (e.g. location of open dumps relative to streams, rivers, or other bodies of water). Within Fig. those standards are shown as S_1, S_2, and S_3. The second class, referred to as conditional, includes standards having acceptable levels which have been locally established and are specified as a range rather than a single value. Here there is a less precise understanding of the relationship between the levels of the standard and the deleterious effect than those included within the first class of standards. An example of a standard within this second class, as shown on Fig. E.2, is the average vermin population density. Finally, in the third class, negotiable, are standards which are related to highly subjective factors and for which the relationships with the associated deleterious effects are almost entirely established by individual or group preference. Thus, based on the importance and/or severity of the deleterious effects, the screen stages are ordered accordingly.

As shown in Fig.E.2, an operation or system, with those characteristics, which are relevant to the standards, is entered into the screen at stage S_1.

PAGE NOT

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DIGITALLY

It should be noted at this point that since the screen is being designed for any solid waste handling system, the number of screen stages (relating to specific standards) would be greater than is required for any individual operation or system. Within this stage, for example, a comparison is made of the particulate emission characteristics, operation or system and the acceptable particulate emission level. Given that either the operation or system does not emit particulate matter, or the acceptance level is not exceeded, the operation or system is advanced to the next stage. If the candidate does not perform within the particulate matter limit, an assessment is made (outside the screen structure) to determine whether appropriate modifications can be made. At this point, if the results of the technical assessment indicates that the modification cannot be made so as to enable the candidate to operate within the acceptable level, the candidate is immediately rejected. In many instances, it can be expected that the modification can be appropriately achieved by utilizing several different approaches. If the approaches are significantly different, their introduction to the inclusion of operation or system can be thought of as generating additional candidates. Thus, another function of the screen and screening procedure is to assist in the formulation of additional alternative operations or systems from the original set of candidates. When appropriate modifications are made, the operation or system is passed on to the following screen stage, S_2.

At the second screen stage (within the immutable class of stages), the operation or system is subjected to a similar comparison. For the example shown in Fig.E.2, the second stage is associated with the gaseous emission (NO_x, SO_x, or hydrocarbon) standard.* Here again, if appropriate modification can not be made, the candidate is discarded. Given that the modification is required and is accomplished, the operation or system is now examined further. At

*Although the gaseous emission standard is depicted as a single stage, each of the constituents would be assessed individually within successive screen stages; the operation or system could be rejected if the level is not met or appropriate modifications could not be accomplished at each stage.

this point an assessment must be made to establish whether the type or extent of the modification made has changed its characteristics in a manner which relates to the previous screen stages. Thus at screen stage S_2, after the modification has been performed, a question is posed as to whether the operation or system particulate emission characteristics has been altered. If no alteration has been made to the characteristics related to the standard, or if the particulate matter acceptance level has not been violated the operation or system is passed through to the S_{i+1} stage, or in this case, S_3.

At the third screen stage, solids in water output standard, the screening procedure is similar to that described for the S_2 screen stage with the one major exception being that, given a modification to the operation or system, the consequences of the modification must be examined relative to all preceding stages. As a result of a modification at this stage or any stage i which has an associative effect relative to a previous standard, it is possible that the candidate is now rejected because of an inability to meet both acceptable levels concurrently.

The second class of stages, conditional, is located within the screen directly after the immutable stages. Since the conditional class consists of standards whose acceptance levels are locally-derived and whose impacts are not precisely understood, the screening process for this class would have the following properties:

(1) As in the immutable class, the operation or system is compared with the acceptance level at stage j. If its appropriate characteristics performance is within the level, the candidate is passed through to the next stage.

(2) Under the condition that the acceptance level is not met, a measurement is made of the difference between the candidate performance and the acceptance level. Depending on the specific standard and the amount of uncertainty

regarding the relationship of the level and the "deleterious" effect(s) the candidate is either passed through or the modification procedure is utilized.

(3) In the event that the candidate must be modified for acceptance at the specific stage, the same process is employed as had been described earlier.

As indicated, the significant difference in screening between the conditional class and the immutable class is the introduction of a step which allows for judgment to be exercised as to the altering of the acceptance level for individual candidates. An example of this class of measure and the screening process is shown in Fig.E.2 as stage S'_1: vermin limit.

The third and last class of stages, negotiable, operates in a similar manner to the above with the major difference being that the acceptance level may be altered significantly, if it appears desirable. In the Figure, the example shown refers to an odor standard. Whereas initially it may have been decided to require that odors be restricted to the building or buildings housing an operation, for certain types of odors it may be acceptable to restrict the odor to the total area occupied by the operation; that is, within the boundaries of the facility. Therefore, instead of rejecting the operation or system since it did not pass the acceptance level and no modification could be made, a question is posed as to whether or not the acceptance level should be altered. If the response to the question is negative, the process or system is discarded, whereas, if the response is positive, a new acceptance level is established and the candidate is passed to the next stage of screening. This procedure is shown on Fig. E.2 as the S''_1 screen stage.

Upon passing through the final screen stage, a determination is made as to whether the alternative being screened is an operation or a solid waste handling system. If the candidate is a system, it is now considered an appropriate alternative for main evaluation and is introduced into the Solid

Waste System Evaluation Model. In the case that the candidate is an operation, the accepted operation is now considered for systems synthesis and subsequent reinsertion into the screen as part of a candidate system. The synthesized system is subject to the identical screening procedure as outlined above.

E.3 Summary

The screen and screening procedure is a systematic approach to the examination of operations and systems to determine whether they meet the acceptance levels associated with the standards prescribed by and/or imposed on the region. The screening/modification procedure of each candidate is useful in rejecting alternatives which cannot meet these standards prior to the more extensive and expensive procedure of system evaluation as described in Section 3, and assisting in the formulation of additional alternatives resulting from the modification step. Given these attributes of the screen and screening procedure, the further development of an efficient, operational screen and screening procedure would provide a useful capability for evaluating large numbers of alternative solid wastes operations and systems.

APPENDIX F INTRODUCING PRIVATE SOLID WASTE HANDLING INTO REGIONAL SOLID WASTE MANAGEMENT PLANNING

F.1 Introduction

A review of numerous county and regional solid waste handling studies has revealed that:

(a) The collection of refuse is being performed by individual municipalities and/or private collectors and recommendations or conclusions are made that collection should not be performed on an integrated country-wide or regional basis. That is, the current organizations and their responsibilities for refuse collection should not be modified.

(b) In recognition of significant increases in population and economic activity, and increases in solid waste generated per capita, it is concluded that available and accessible (near sources of refuse generation) landfill sites are rapidly disappearing.

(c) Data and estimates pertaining to household refuse generation rates, municipal collection, processing and disposal functions are presented and analyzed in considerable detail. Very little, if any, information concerning refuse generated by sources not serviced by municipal systems, and private collection processing and disposal practices, is included.

(d) The conclusions and recommendations made refer to the "public sector" with little or no regard to the current and/or potential interactions between this sector and the private sector with respect to processing and disposal operations. Whereas the severity of the municipal problems are described, and short as well as long-term solutions recommended, the implications left by these studies are that the problems of the private sector are not severe or that many alternative solutions to their problems are available. In addition, it can be inferred that there is little or no need to consider the interactions between these two sectors, and the mutual benefits of coordinated processing and disposal functions.

It is this dichotomization of the regional solid waste management problem which bears further study to determine whether or not these sectors should be treated dependently and if so, in what manner. It is recognized that both sectors compete for the available capacity of "close-in" landfill sites and although their objectives may differ somewhat, there appears to be various bases for cooperation which can be arrived at by quantitative study. The material presented in this Appendix is a discussion of the objectives of the individual sectors; a description of an aspect of mutual cooperation; and a presentation of an illustrative example which highlights, in economic and land use terms, the advantages which each sector could accrue on a short-term as well as a long-term basis through cooperation. It should not be inferred that the identical solution will be applicable to all regions since there are obvious differences in refuse generated rates, location and availability of landfill sites, ordinances prohibiting certain forms of refuse processing, etc. The main purpose of this preliminary look at this question is to explore the implications of cooperation between the private and public refuse handling systems.

F.2 Common and Diverse Objectives of Public and Private Solid Waste Management

The study of solid waste handling problems in urban areas, metropolitan districts, county and regional levels involves projections of population, economic activity and land-use developments over a period of 25 to 35 years. Utilizing these projections, gross estimates can then be made of the residential, commercial and industrial solid waste quantities to be generated, the locations of refuse generation, and the available land for refuse processing and disposal operations, for these future periods. A cost analysis of alternative processing and disposal operations can be performed and finally, recommendations can be derived which are predicated on fulfilling some long-term objectives in an orderly, time phased plan of action.

A commonly used form of objective function is the minimization of direct cost over some specified time period subject to a number of qualitative constraints such as health standards, aesthetic considerations, political realities, public reaction, etc. A major attribute of the public sector solid waste handling system objective should be, and often is, the long time period being planned for rather than solutions which are derived for year to year, or short-term system operation. Two aspects of the problem which have introduced the need for examining solid waste management on a long-term basis are (i) the requirement for large capitalization systems (amortized over 20 or more years) and ii) the dwindling supply of land which is available and suitable for solid waste processing and disposal. The scarcity of land is referred to consistently when conclusions and recommendations for refuse handling are made.

In considering the objectives and operations of the private solid waste collector and his waste handling problems, it becomes apparent that this economic activity is organized and performed in a manner which is similar to that of many profit-making organizations. Depending on the size of the individual private solid waste collector's organization, the objectives and operations are designed primarily to maximize profits over relatively short-time periods - on a month to month or year to year basis. Thus, ways and means for reducing costs or conversely, increasing profits, independent of the mid-range or long-term community or regional objectives, are sought and readily adopted by the private sector. In view of the relatively fast amortization periods used for their equipment, and the relatively small investment made on fixed facilities, these organizations can be properly characterized as "foot-loose". This is not to say that they are established for short-term service but rather, their commitments to performing the refuse collection and disposal functions are entirely dependent on the economic factors which govern their profit structure.

With these two seemingly opposed objectives, it may be questionable as to whether these two sectors - public and private - could cooperate in meeting the total solid waste handling needs of a city, district, county or region, and still enable each sector to achieve its objectives, at least in part.

In addition to the differences in objectives, an area of competition between the two sectors is the demand for a scarce resource - land. For the private sector, this scarce resource can be thought of in terms of the cost entailed in hauling refuse to disposal sites which will be located further and further away from the points of collection. The public sector is also confronted with this same consideration and in addition, the political reality of the uncertainties when utilizing land outside their jurisdictions. This uncertainty stems from the difficulties of obtaining acceptance of another political entity to allow it to utilize their land for disposal purposes on a long-term, uninterrupted basis.

Assuming for the time being that one can view the collection function as being relatively independent of the processing and disposal functions, it is evident that the existence of private collection organizations is beneficial because one result of their activity is reduction of the requirement for the general community to provide this service. In some communities where all the refuse is collected by private organizations, the individual household and other refuse producers pay directly for the performance of this service. Another mode of payment for collection services provided by the private sector is to have the community enter into a contractual arrangement with the refuse collecting organization, and incorporate these costs into the overall community budget. In other communities, the households are serviced by the public sector, and commercial and industrial organizations are handled by the private sector. This latter arrangement normally results in a service designed to be more responsive to the specific needs of the individual commercial and industrial organization being serviced.

When considering the processing and disposal functions, it is not apparent that similar arguments for decentralization are valid. In general, processing requires rather large, expensive, fixed installations which are either beyond the fiscal resources of the individual private collector or are not in consonance with their individual objectives. The processing facilities do not dispose of the refuse but rather modify the weight, volume or chemical properties of the input. Unless one can establish that this processing function results in a net profit to the private organization, there are few, if any, economic incentives for the private sector to process the refuse. To date, except for refuse-compaction processing, and a limited number of highly local situations, the processing operations in the United States have not been justified on the basis of a "profit" being derived by the operator of the facility. However, it has been shown that as the volume or tonnage of refuse being processed by a facility increases, the unit cost of processing is reduced substantially.

A significant advantage derived from refuse processing is the conservation of the available sanitary landfill capacity. This advantage is of mutual benefit to both sectors and thus serves as a basis for an investigation of the conditions and means required to bring about this cooperative action. Within any investigation of cooperative actions, explicit attention must be given to the objectives of each sector over its respective time span of interest. A preliminary model and an illustrative example is presented to highlight some of the points made and to provide further insights for examining the hypothesis that cooperation between the public and private sectors would result in mutual benefits. Thus, given a range of regional and technological inputs, the model should assist regional planning in examining ways and means for achieving mutual cooperation between the private and public sectors in the processing and disposal of solid waste.

F.3 Preliminary Model

A preliminary model is presented for examining the question of cooperation. The model is exercised under two conditions -- cooperative and noncooperative operations -- and results are derived upon which comparisons can be made. Briefly described the two systems to be examined are:

(1) A waste management system (including processing and disposal only) within which the public sector operates independently of the private sector. Within this system both sectors utilize the same disposal facilities but only the public sector processes its refuse.

(2) A waste management system within which all the refuse is processed and then disposed of at the same disposal facilities.

Each of these systems is formulated in terms of the direct costs to the public and private sectors and results are derived relative to land requirements as a function of elapsed time of system operation. So as to allow for a preliminary assessment of the systems to be made, the following assumptions are utilized within the model.

(a) The publicly -controlled or operated (municipal or region) and privately-operated collection function are performed independently

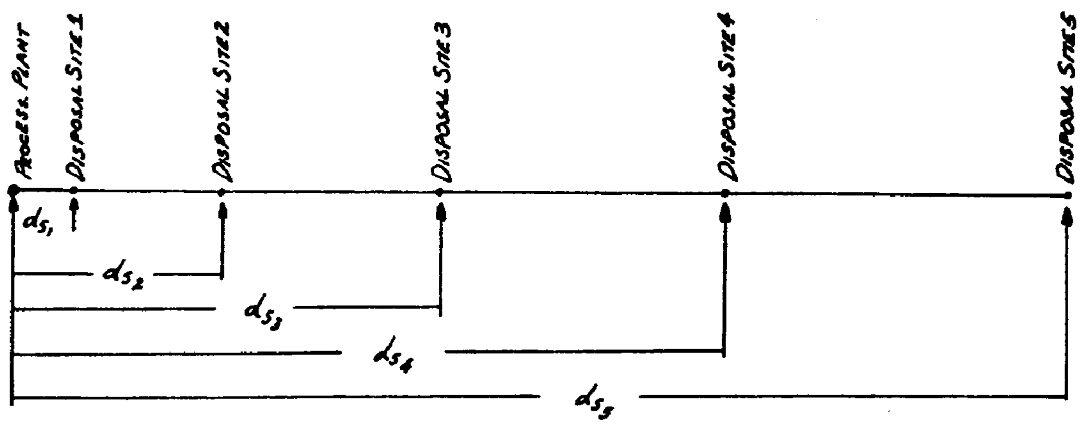
(b) The collection costs are not included within the determination of refuse handling

(c) The cost components included in establishing the refuse handling cost include (i) processing costs; (ii) round-trip transportation costs to the disposal site; and (iii) disposal costs.

(d) Within System (1), the publically-constructed and operated processing plant maintains a three-shift, five day per week schedule and has a capacity which is sufficient to handle the total quantity of public sector refuse. When the private sector utilizes the same processing facilities as the public sector (System 2), the plant capacity can be increased to accommodate the additional refuse within a three shift, five day per week schedule.

(e) Refuse (processed or unprocessed) is hauled to the nearest disposal site until such time as the site capacity is exhausted. Each sector's refuse is handled at the disposal sites on a first come - first served basis; that is, no preferential treatment is given to either sector in terms of site capacity allocation and reservation, or cost per load disposed.

(f) Refuse generation sources are distributed in such a manner that there is no significant difference in transportation costs between hauling refuse to the processing plant or directly to the disposal site.



[Note: Although the disposal sites are all shown located along a straight line, they are located, more appropriately, within a two-dimensional space.]

Figure F.1 LOCATION OF DISPOSAL SITES RELATIVE TO SINGLE PROCESSING PLANT

F.3.1 Processing Plant Parameters

ρ = reduction ratio of process; for municipally or cooperatively - operated processing plant, (initial weight of solid waste is that within collection vehicle at time of delivery to processing plant)

ρ' = reduction ratio of processing plant (employing a different process than above) operated by private sector (e.g., compaction associated with transfer station)

c_p = cost/ton of municipally-operated processing plant of capacity $C_p (C_p \geqq R_M)$ (\$/ton)

c'_p = cost/ton of cooperatively-operated processing plant of capacity C'_p $(C'_p \geqq R_M + R_p)$ (\$/ton)

c''_p = cost/ton of privately-operated processing plant of capacity C''_p $(C''_p = R_p)$ (\$/ton)

F.3.2 Refuse Collected Parameters

R_M = municipally collected, or privately-collected, municipal solid waste (tons/day)

R_p = commercial and industrial refuse collected by private sector (tons/day)

D = density of refuse (in vehicle) collected by public and private sectors delivered to processing plant. In the general case, the average density (D) of refuse collected by the public sector is different than that of the private sector (lbs/cu. yd)

3.3 Transportation Parameters

C_T = capacity of municipal vehicles used for transporting processed refuse (yd^3/truck)

C'_T = capacity of private vehicles used for transporting processed or unprocessed refuse (yd^3/truck)

c_t = cost/mile of municipal vehicles for transporting processed refuse ($/mile)

c'_t = cost/mile of private vehicle for transporting processed or unprocessed refuse ($/mile)

3.4 Disposal Site Parameters

C_{s_i} = capacity of site i (yd^3)

c_s = cost of disposing of truck load (capacity C_T) ($/truck load)

c'_s = cost of disposing of truck load (capacity C'_T)($/truck load)

d_i = distance of disposal site i from processing plant (miles)

3.5 Life of Disposal Site i

Case 1 - Site receives processed municipal refuse and unprocessed private sector refuse

$$L_{s_i} = \frac{DC_{s_i}}{\rho R_M + R_P}$$

Case 2 - Site receives municipal refuse and private sector refuse - all refuse processed in identical fashion

$$L_{s_i} = \frac{DC_{s_i}}{\rho(R_M + R_p)}$$

Case 3 - Site receives processed municipal refuse and private sector refuse - each sector employs different process

$$L_{s_i} = \frac{DC_{s_i}}{\rho R_M + \rho' R_p}$$

F.3.6 System (1) - Municipal Solid Waste Processed and Disposed - Private Waste Disposed Directly

TC_M = Total Cost to Public Sector Over Life of Disposal Sites

$$= c_\rho R_M \left[\sum_i \frac{DC_{s_i}}{\rho R_M + R_p} \right] + \left(\frac{\rho R_M}{DC_T} \right) (2c_t) \left[\sum_i \frac{DC_{s_i} d_i}{\rho R_M + R_p} \right] + \frac{c_s \rho R_M}{DC_T} \left[\sum_i \frac{DC_{s_i}}{\rho R_M + R_p} \right]$$

$$= \left(c_\rho R_M + \frac{c_s \rho R_M}{DC_T} \right) \left[\sum_i \frac{DC_{s_i}}{\rho R_M + R_p} \right] + \frac{2 \rho R_M c_t}{DC_T} \left[\sum_i \frac{DC_{s_i} d_i}{\rho R_M + R_p} \right]$$

TC_p = Total Cost to Private Sector Over Life of Disposal Sites

$$= \frac{R_p}{DC_T'} (2c_t') \left[\sum_i \frac{DC_{s_i} d_i}{\rho R_M + R_p} \right] + \frac{C_s' R_p}{DC_T'} \left[\sum_i \frac{DC_{s_i}}{\rho R_M + R_p} \right]$$

Subject to condition:

$$\frac{1}{D} \left[\rho R_M(t) + R_p(t) \right] = \sum_i c_{s_i}$$

F.3.7 System (2) - <u>Both Municipal and Private Solid Waste Processed Within Cooperative Processing Facility and Then Disposed</u>

TC_M = Total Cost to Public Sector Over Life of Disposal Sites

$$= c_p' R_M \left[\sum_i \frac{DC_{s_i}}{\rho(R_M + R_p)} \right] + \frac{\rho R_M}{DC_T}(2c_t) \left[\sum_i \frac{DC_{s_i} d_i}{\rho(R_M + R_p)} \right]$$

$$+ c_s \frac{\rho R_M}{DC_T} \left[\sum_i \frac{DC_{s_i}}{\rho(R_M + R_p)} \right]$$

$$= \left(c_p' R_M + \frac{c_s \rho R_M}{DC_T} \right) \left[\sum_i \frac{DC_{s_i}}{\rho(R_M + R_p)} \right] + \frac{2\rho R_M c_t}{DC_T} \left[\sum_i \frac{DC_{s_i} d_i}{\rho(R_M + R_p)} \right]$$

TC_p = Total Cost to Private Sector Over Life of Disposal Sites

$$= c_p' R_p \left[\sum_i \frac{DC_{s_i}}{\rho(R_M + R_p)} \right] + \frac{\rho R_p}{DC_T'} \left[\sum_i \frac{DC_{s_i} d_i}{\rho(R_M + R_p)} \right]$$

$$+ c_s' \frac{\rho R_p}{DC_T'} \left[\sum_i \frac{DC_{s_i}}{\rho(R_M + R_p)} \right]$$

$$= \left(c_p' R_p + \frac{c_s' \rho R_p}{DC_T'} \right) \left[\sum_i \frac{DC_{s_i}}{\rho(R_M + R_p)} \right] + \frac{2\rho R_p c_t'}{DC_T'} \left[\sum_i \frac{DC_{s_i} d_i}{\rho(R_M + R_p)} \right]$$

System (2A) - <u>Both Municipal and Private Solid Waste Processed Within Different Processing Facilities and Then Disposed</u>

TC_M = Total Cost to Public Sector Over Life of Disposal Sites

$$= c_p R_M \left[\sum_i \frac{DC_{s_i}}{\rho R_M + \rho' R_p} \right] + \frac{\rho R_M}{DC_T}(2c_t) \left[\sum_i \frac{DC_{s_i} d_i}{\rho R_M + \rho' R_p} \right]$$

$$+ \frac{c_s \rho R_M}{DC_T} \left[\sum_i \frac{DC_{s_i}}{\rho R_M + \rho' R_p} \right]$$

$$= \left(c_p R_M + \frac{c_s \rho R_M}{DC_T}\right)\left[\sum_i \frac{DC_{s_i}}{\rho R_M + \rho' R_p}\right] + \frac{2\rho R_M c_t}{DC_T}\left[\sum_i \frac{DC_{s_i} d_i}{\rho R_M + \rho' R_p}\right]$$

TC_p = **Total Cost to Private Sector Over Life of Disposal Sites**

$$= c''_p R_p \left[\sum_i \frac{DC_{s_i}}{\rho R_M + \rho' R_p}\right] + \frac{\rho' R_p}{DC'_T}(2c'_t)\left[\sum_i \frac{DC_{s_i} d_i}{\rho R_M + \rho' R_p}\right]$$

$$+ c'_s \rho' R_p \left[\sum_i \frac{DC_{s_i}}{\rho R_M + \rho' R_p}\right]$$

$$= \left(c''_p R_p + \frac{c'_s \rho' R_p}{DC'_T}\right)\left[\sum_i \frac{DC_{s_i}}{\rho R_M + \rho' R'_p}\right] + \frac{2\rho' R_p c'_t}{DC'_T}\left[\sum_i \frac{DC_{s_i} d_i}{\rho R_M + \rho' R_p}\right]$$

F.3.8 Illustrative Example

R_M = 1000 tons/day

R_p = 1000 tons/day

D = 400 lbs/yd^3 = .2 tons/yd^3

ρ = .2

c_p = \$5/ton

c'_p = \$4/ton

C_{s_1} = 200,000 yd^3 d_{s_1} = 5 miles

C_{s_2} = 400,000 yd^3 d_{s_2} = 10 miles

C_{s_3} = 800,000 yd^3 d_{s_3} = 15 miles

C_{s_4} = 1,600,000 yd^3 d_{s_4} = 20 miles

C_{s_5} = 3,200,000 yd^3 d_{s_5} = 25 miles

C_T = 40 yd^3/load

C'_T = 40 yd^3/load

c_t = \$1/mile

c'_t = \$1/mile

c_s = \$10/load = \$10 per 40 yd^3 of residue

c'_s = \$10/load = \$10 per 40 yd^3 of residue or refuse

F.4 Results and Conclusions

A number of conclusions can be drawn based on the results derived within the illustrative example but in all instances these conclusions should be viewed as trends or directions rather than as estimates of the savings in total system cost if a cooperative system is adopted. As another note of caution, it is important that the initial assumptions utilized be kept in mind as well as the parameters employed within the illustrative example when assessing the results and attempting to utilize them within a specific region.

An examination of Table F.1 and Figs. F.2, F.3 and F.4, reveals the fact that if the planning for a regional solid waste system is predicated on a long-term basis, and if there is a relative scarcity of close-in and available land for refuse disposal, it appears advantageous to introduce a processing function which is utilized by all sectors which perform refuse disposal. This advantage (shown on Fig. F.4), in terms of direct costs, is immediately experienced by the public sector and, within a short time, by the private sector. Within the illustrative example, the costs associated with System (1) rise steeply, especially for the private sector, as the disposal operation shifted from Site 4 to Site 5, whereas the costs associated with

Table F.1
PUBLIC AND PRIVATE REFUSE SYSTEM COSTS

Disposal Site(i)	Life of Disposal Site (Days)	Elapsed Time (Days)	Public Total Cost*	Private Total Cost**	Public Acc. Total Cost	Private Acc. Total Cost	Public & Private Acc. Total Cost
SYSTEM (1)	**Non-Cooperative Operations**						
1	33	33	$ 181,500 (5500)	$ 82,500 (2500)	$ 181,500 (5500)	$ 82,500 (2500)	$ 264,000 (8000)
2	67	100	566,700 (8460)	333,700 (4980)	748,200 (7480)	416,200 (4100)	900,400 (11,640)
3	133	233	1,364,700 (10,260)	998,700 (7510)	1,931,400 (8290)	1,332,400 (5720)	3,263,800 (14,010)
4	267	500	3,023,500 (11,320)	2,627,500 (9840)	4,954,900 (9910)	3,959,900 (7920)	8,914,800 (17,830)
5	534	1034	6,494,500 (12,160)	6,632,500 (12,420)	11,349,400 (10,980)	10,292,400 (9950)	21,641,800 (20,930)
SYSTEM (2)	**Cooperative Operations**						
1	100	100	$ 450,000 (4500)	$ 450,000 (4500)	$ 450,000 (4500)	$ 450,000 (4500)	$ 900,000 (9000)
2	200	300	950,000 (4750)	950,000 (4750)	1,400,000 (4670)	1,400,000 (4670)	2,800,000 (9340)
3	400	700	2,000,000 (5000)	2,000,000 (5000)	3,400,000 (4860)	3,400,000 (4860)	6,800,000 (9720)
4	800	1500	4,200,000 (5250)	4,200,000 (5250)	7,600,000 (5070)	7,600,000 (5070)	15,200,000 (10,140)
5	1600	3100	8,800,000 (5500)	8,800,000 (5500)	16,400,000 (5290)	16,400,000 (5290)	32,800,000 (10,580)

(   ) Refer to Daily Costs

*System (1) and (2) Cost of Processing and Disposal.

**System (1) Cost of Disposal and System (2) Cost of Processing and Disposal.

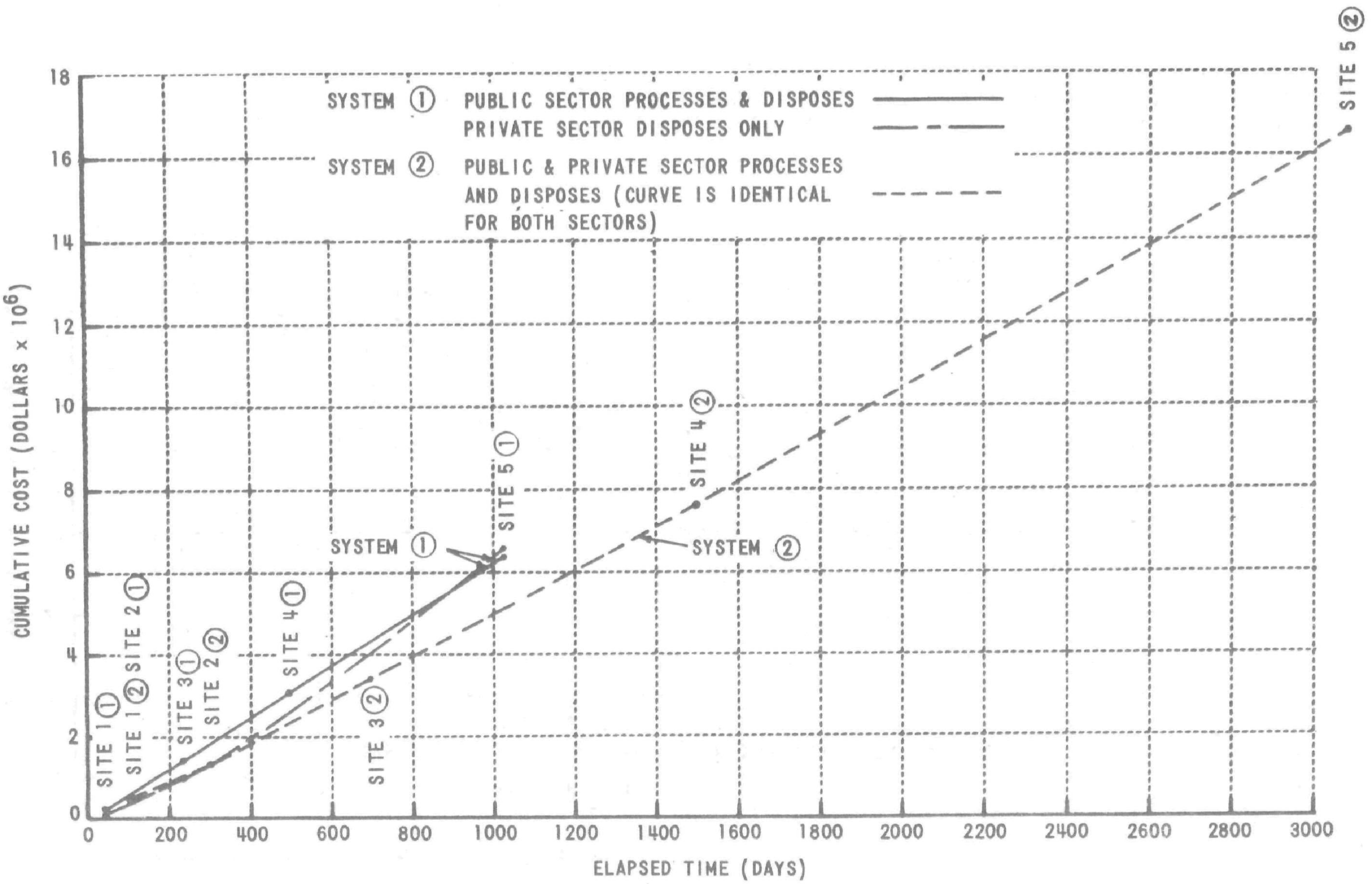


Figure F.2 CUMULATIVE COST FOR PUBLIC AND PRIVATE SECTORS VS ELAPSED TIME

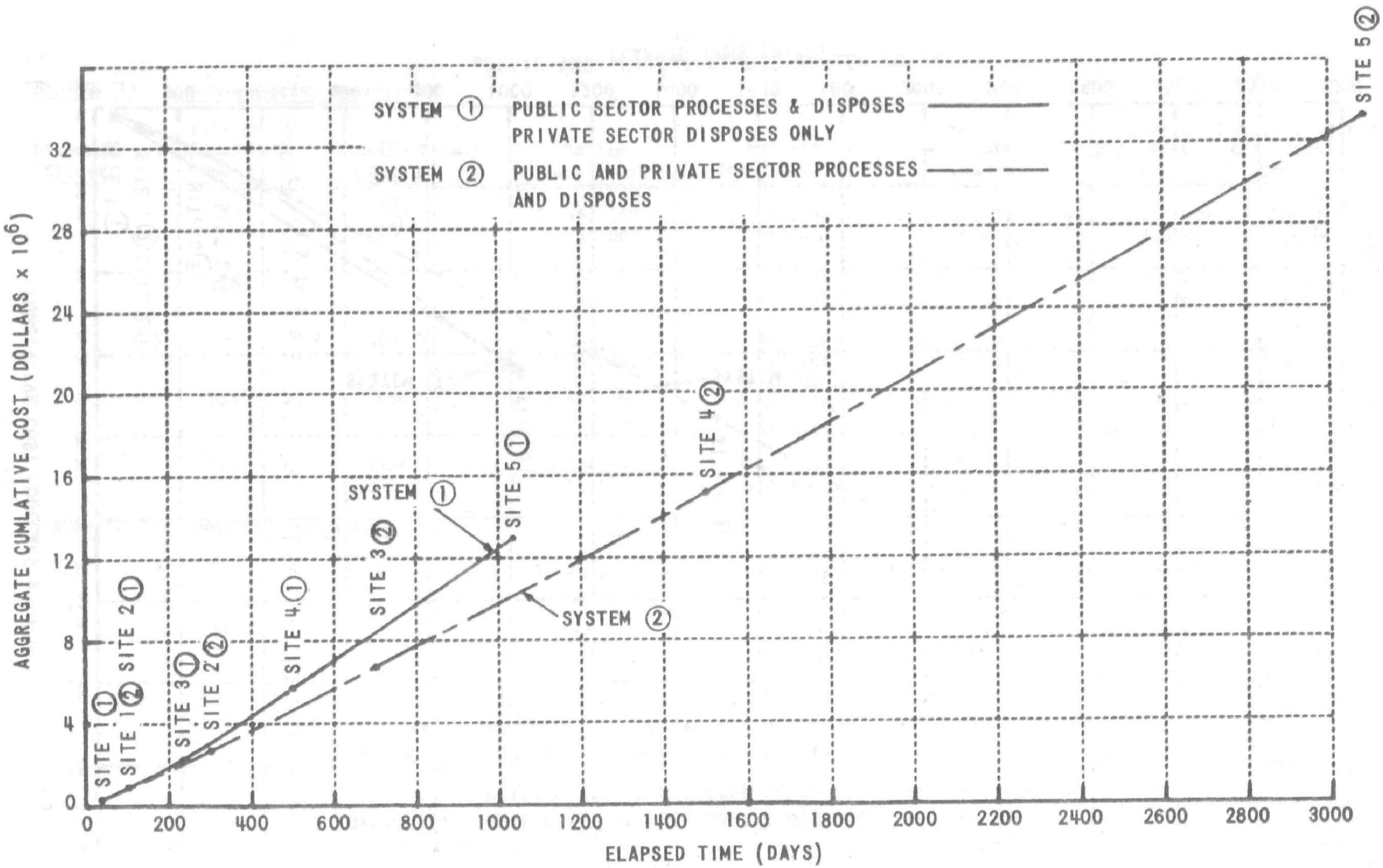


Figure F.3 AGGREGATE CUMULATIVE COST VS ELAPSED TIME

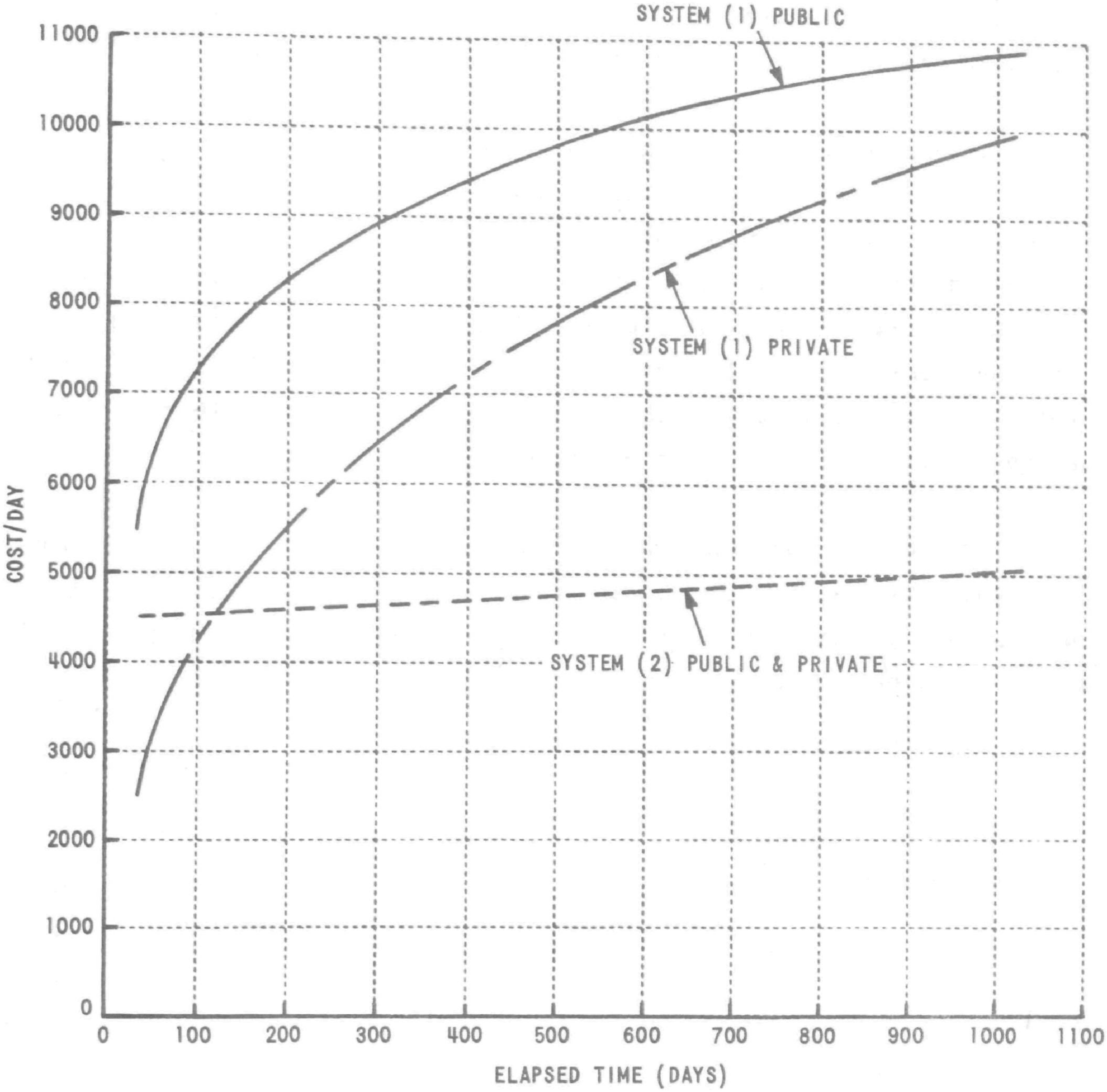


Figure F.4 COST PER DAY FOR PUBLIC AND PRIVATE REFUSE HANDLING SYSTEMS

System (2), although increasing, increased at a much slower rate. These findings are shown more directly on Fig. F.2.

Depicted on Figs.F.2 and F.3 is a time history of the utilization of the disposal sites under the two systems. Although this time history is related to the total amount of refuse collected, the amount which is processed and the process reduction coefficient, ρ , the impact of the different utilization rates of the available land fill capacity is made evident by these illustrative results. Here again, it is not significant to note the specific values on the abscissa scale but rather to note the relative capacity utilization rates of the disposal sites.

In conclusion, there are indications that a regional processing and disposal plan, which includes the public and private sectors should result in savings for both sectors, and in more effective utilization of the available land fill capacity.

APPENDIX G ESTIMATION OF OPERATING COSTS FOR REFUSE TRANSPORTATION IN THE CITY OF BUFFALO

G.1 Summary

Records kept by the City of Buffalo do not contain odometer readings on serial-numbered refuse trucks, nor are cost records kept in sufficient detail on collection truck fleet operations to allow for determining the cost of transporting refuse. Nevertheless a rough estimate of transportation costs per mile was derived by means of estimating total operating costs and the total number of miles required to perform typical weekly operations. The estimate of cost per mile for transporting refuse does not include the amortized cost of the truck or the labor cost of a crew or driver; these costs are approximately 65 cents per mile during the year 1966. When amortization and labor costs are included, the cost of transportation while performing the transport(exclusive of direct refuse collection) function is approximately 89 cents per mile.

G.2 Method of Estimation

Approximately two-thirds of the "Servicing Auto Equipment" account, which amounts to $1.05 million in the City of Buffalo Department of Streets and Sanitation budget for 1966, is attributable to collection and transport. The remainder of the funds within the "Servicing Auto Equipment" account is attributable to an assortment of functions including snow-removal, dog pound operation, and street-cleaning. Thus the weekly cost of operation of trucks for collection and disposal purposes is approximately (2/3) (1.05/52)million dollars, or $13,462 per week. This cost is divided by an estimate of the number of miles covered in one week by the entire truck fleet to obtain an operating cost per mile. The estimate of the weekly miles traveled is derived by the method whose description follows.

All calculations are based on a truck fleet of 106 trucks; an average of 99 trucks are in operation at any one time. It was estimated that six to eight trucks are usually under repair or maintenance. The 99 operating trucks make the following trips during an average week:

(a) All streets in Buffalo are traversed twice, once for the regular refuse collection and once for the trash collection.

(b) Each truck travels to its assigned district every day.

(c) Each truck makes several round trips to its assigned incinerator, or one of the two landfills.

(d) Each truck makes a final one-way trip, assumed to be to one of the landfills.

(e) Each truck returns to the garage after discharging its final load of the day.

(f) The residue from the East Side Incinerator is hauled to the Squaw Island Landfill. Since the Squaw Island Landfill is adjacent to the West Side Incinerator, only negligible mileage is involved in hauling West Side Incinerator residue.

This breakdown of all distances traversed by the truck fleet into "trip types" enables the weekly total miles to be estimated as follows:

$$\text{AVERAGE MILES PER WEEK} = M_1 + M_2 + M_3 + M_4 + M_5 + M_6$$

where:

M_1 = 2 [TOTAL NO. OF MILES OF STREETS IN BUFFALO]

M_2 = (5) (99) [AV. DISTANCE FROM GARAGE TO COLLECTION DISTRICT]

M_3 = 2 [AV. NO. OF TRUCKLOADS TO INCINERATORS PER WEEK] [AV. DISTANCE FROM COLLECTION DISTRICT TO INCINERATOR]

M_4 = (5) (2 [AV.NO. OF TRUCKLOADS TO LANDFILLS PER DAY] - 1) [AV. DISTANCE FROM DISTRICT TO LANDFILL]

M_5 = (5) (99) [AV. DISTANCE FROM LANDFILL TO GARAGE]

M_6 = 2 [AV. NO. OF TRUCKLOADS OF RESIDUE FROM EAST SIDE INCINERATOR PER WEEK] [DISTANCE FROM EAST SIDE INCINERATOR TO SQUAW ISLAND LANDFILL]

All quantities in brackets were estimated by means of map measurements and by use of data obtained from the City of Buffalo on truckload deliveries to the various facilities, and on truckload quantities originating in the various collection districts during 1966.

Distance and location data which are basic to the various calculations are given in Table G.1. The approximate centroid of each collection district was located (by visual estimation) with respect to an arbitrary coordinate system, as were the locations of the incinerators, landfills, and the garage. Given these locations, straight line distances from the districts to the facilities, and among the facilities, could be calculated; these are the figures appearing in Table G.1. As will be seen, after all mileage calculations are completed on a straight line basis, the actual miles traveled (as the trucks are constrained to the street network) were obtained by multiplying the straight line distances by the factor 1.3. This correction factor was obtained empirically by a series of map exercises. It is by no means well-established, but is presented as the best estimate currently available for adjusting straight line distances to the distances actually traveled within a city street grid network.

Table G.1

LOCATION AND DISTANCE INFORMATION,
REFUSE COLLECTION DISTRICTS AND FACILITIES, CITY OF BUFFALO

COLLECTION DISTRICT	COORDINATES	ASSIGNED INCINERATOR	DISTANCE TO INCINERATOR	"ASSIGNED" LANDFILL	DISTANCE TO LANDFILL	DISTANCE TO GARAGE
1	2.5, 4.7	W	4.08	S	4.08	0.53
2	2.0, 5.4	W	3.25	S	3.25	1.30
3	2.5, 6.7	W	2.38	S	2.38	1.87
4	1.4, 6.1	W	2.42	S	2.42	2.00
5	1.4, 7.0	W	1.54	S	1.54	2.64
6	2.0, 8.0	W	1.51	S	1.51	3.26
7	1.0, 9.4	W	2.00	S	2.00	4.92
8	2.2, 9.1	W	1.89	S	1.89	4.67
9	3.5, 8.7	W	2.87	L	1.80	3.83
10	3.5, 9.8	W	3.34	L	1.77	4.92
11	4.7, 9.3	W	4.19	L	0.50	4.72
12	4.1, 7.8	W	3.41	L	1.86	3.10
13	5.0, 7.7	E	3.53	L	1.61	3.44
14	4.2, 6.6	E	3.11	S	3.44	2.08
15	3.2, 6.0	W	3.37	S	3.37	1.30
16	3.2, 5.0	E	3.34	S	3.74	0.50
17	4.0, 4.5	E	2.50	S	4.62	1.08
18	4.5, 5.7	E	2.33	S	4.16	1.70
19	3.2, 3.5	E	3.44	S	5.07	1.60
20	5.0, 2.2	E	2.75	S	7.07	3.36
21	6.0, 2.6	E	1.96	S	7.36	3.78
22	6.3, 4.7	E	1.20	L	4.73	3.31
23	5.4, 4.5	E	1.60	S	5.61	2.43
24	5.4, 6.4	E	2.15	L	2.92	2.92
25	6.2, 6.8	E	2.32	L	2.69	3.72
26	6.1, 8.0	E	3.52	L	1.58	3.10
27	5.9, 9.3	E	4.84	L	0.90	5.27
E.S. INCINERATOR	6.5, 4.5			S	6.89	3.52
SQUAW ISLAND	1.1, 8.1					3.83
LASALLE L.F.	5.2, 9.3					3.81
GARAGE	3.0, 4.9					

Other basic data utilized consist of the tonnage figures transported to the incinerators, which are identified by originating district, and the cubic yardage delivered to the landfills, which are similarly identified. The 1966 totals over all districts and over the entire year yield the following averages:

Av. Truckload to Incinerator = 2.6 tons

Av. Truckload to Landfill = 14.2 cu. yd.

Checks on data sets which are restricted geographically and in time revealed that these relationships remain sufficiently stable to be of use as conversion factors. With this information, all quantity data could be stated in terms of numbers of truckloads. Having performed this conversion on all quantity data, it was possible to give the following for each collection district i, $1 \leq i \leq 27$:

U_i = the total number of truckloads from i delivered to incinerators

V_i = the total number of truckloads from i delivered to landfills

W_i = the total number of truckloads originating in i

$= U_i + V_i$

This quantity data is given in Table G.2. In order to aggregate the total number of truckloads, the following definitions are employed:

$U = \sum U_i$ as the total number of truckloads delivered to incinerators

$V = \sum V_i$ as the total number of truckloads delivered to landfills

$W = \sum W_i$ as the total number of truckloads of refuse

Table G.2

REFUSE QUANTITY INFORMATION, CITY OF BUFFALO, 1966
NUMBER OF TRUCKLOADS GENERATED DURING THE YEAR

COLLECTION DISTRICT	INCINERATED	DISPOSED AT LANDFILLS	TOTAL TRUCKLOADS	WEIGHTS		
				u_i	v_i	w_i
1	1993	1170	3163	0.0311	0.0561	0.0372
2	2370	1221	3591	0.0370	0.0585	0.0423
3	2023	1541	3564	0.0315	0.0739	0.0419
4	2367	698	3065	0.0369	0.0335	0.0361
5	2679	682	3361	0.0418	0.0327	0.0395
6	1962	753	2715	0.0306	0.0361	0.0319
7	3254	556	3810	0.0507	0.0267	0.0448
8	1989	706	2695	0.0310	0.0338	0.0317
9	1815	316	2131	0.0283	0.0151	0.0251
10	1963	595	2558	0.0306	0.0285	0.0301
11	1945	758	2703	0.0303	0.0363	0.0318
12	2548	774	3322	0.0397	0.0371	0.0391
13	1665	700	2365	0.0260	0.0336	0.0278
14	2666	728	3394	0.0416	0.0349	0.0399
15	2835	536	3371	0.0442	0.0257	0.0397
16	2295	1504	3799	0.0358	0.0721	0.0447
17	2925	788	3713	0.0456	0.0378	0.0437
18	3644	725	4369	0.0568	0.0348	0.0514
19	1645	562	2207	0.0257	0.0269	0.0260
20	3537	781	4318	0.0552	0.0374	0.0508
21	3142	770	3912	0.0490	0.0369	0.0460
22	2343	516	2859	0.0365	0.0247	0.0336
23	2312	630	2942	0.0361	0.0302	0.0346
24	1965	702	2667	0.0306	0.0337	0.0314
25	1795	727	2522	0.0280	0.0349	0.0297
26	2272	655	2927	0.0354	0.0314	0.0344
27	2177	765	2942	0.0339	0.0367	0.0346
TOTALS	64126	20860	84986	1.0000	1.0000	1.0000

Weighting factors, $u_i = U_i/U$, $v_i = V_i/V$, $w_i = W_i/W$, are now computed which are of use in establishing average distances for the various trip types. These weighting factors are included in Table G.2 in the last three columns.

Specifically, if d'_i is the distance given in Table G.1 from the garage to the centroid of district i, then:

Av. distance from garage to collection district $= D_2 = \sum w_i d'_i$

This distance is 2.777 mi.

The refuse from each district is transported to one of the two incinerators based on the 1966 practices of the city of Buffalo. The fact that in emergencies the alternative incinerator is sometimes used is ignored. An examination of the records indicate that this does not occur often enough to exert a significant influence on the outcome. Therefore it is possible to assign to each collection district i, a distance d''_i to the appropriate incinerator. The "assigned" incinerator and the distances to it appear in Table G.1. With these inputs, the average distance from the collection district to the assigned incinerator is:

Av. distance from collection district to assigned incinerator $= D_3 = \sum u_i d''_i$

This average distance is 2.721 mi.

No explicit assignment of collection districts to the two landfills was in existence. However, the total cubic yardages delivered to the two sites during the year was known. Using these totals, an assignment could be artificialized in which the collection districts closest to the LaSalle landfill were assigned to that facility until the total of the V_i figures associated with those districts approximated as nearly as possible the actual total delivered to the LaSalle landfill. This "assignment"is indicated in Table G.1 for each collection district, along with the distance d''_i to that landfill. Then:

Av. distance from collection district to landfills = $D_4 = \sum v_i d_i'''$

This average distance is 3.146 mi.

With these three averages computed, calculation of the mileage estimates, $M_1, \ldots M_6$, defined previously, and hence the per mile cost estimate, can be made.

G.3 Calculation of the M-Quantities and the Cost Estimate

Since the number of miles of streets in the City of Buffalo is 620 miles, $M_1 = 2 \times 620 = 1240$ miles/wk. The distance traveled from the garage to the collection districts, is $M_2 = 5 \times 99 \times 2.777 = 1375$ miles/wk, using the average distance $D_2 = 2.777$ miles.

To compute M_3, one needs to know the average number of truckloads delivered to the incinerators per week. This is given by (U/52) = (64126/52)= 1233.2 truckloads/wk. Using the average distance $D_3 = 2.721$ miles, given previously, $M_3 = 2 \times 1233.2 \times 2.721 = 6711$ miles/wk.

To compute M_4, one needs the quantity $D_4 = 3.146$ miles from the previous section and also the average number of truckloads delivered to the landfills per day. Based on a 260 day year, the latter quantity is given by (V/260) = (20,860/260) = 80.23 truckloads/da. Then $M_4 = 5[2(80.23) - 1] \times 3.146 = [10(80.23) - 5] \times 3.146 = 797.3 \times 3.146 = 2508$ miles/wk.

Computation of M_5 in the present case is simplified by the fact that the distances from the garage to the two landfills are just about equal, that is, 3.82 miles for each. Thus $M_5 = 5 \times 99 \times 3.82 = 1891$ miles/wk.

To compute M_6, the average number of truckloads of residue hauled per week from the East Side incinerator is known. This figure, which does not appear in either of the tables, is 169 truckloads per week. Since the distance from the East Side incinerator to the Squaw Island landfill is 6.9 miles, the estimate $M_6 = 2 \times 169 \times 6.9 = 2332$ miles/wk.

The sum $M_1 + \dots + M_6$ = 16,057 miles/wk. which represents the straight line distance estimation. As discussed previously, this figure is multiplied by 1.3 to account for the fact that the actual truck travel is constrained to the road network. On that basis, the average is 16,057 x 1.3 = 20,874 miles/wk. This results in an average operating cost of ($13,462/20,874)= $.645 per mile. This estimate does not include any portion of the cost of the vehicle, nor does it include labor costs for a driver or crew.

G.4 Other Cost Components

Depending on the application, there may be need to add other cost components to the vehicle operating cost alone. For considering use of the vehicle within the transport function (i.e. separating the round trips to the incinerators and landfills apart from the collection function) it probably makes sense to include the cost of the vehicle amortized over all miles covered by the vehicle. Assuming the seven-year amortization period used by the City of Buffalo, the average number of miles covered is

$$\frac{20{,}874 \text{ mi/wk} \times 52 \text{ wks/yr} \times 7 \text{ yr}}{106 \text{ vehicles}} = 71{,}681 \text{ miles}$$

per vehicle. Assuming an approximate $12,000 per vehicle, this increases the cost by an additional 16.8 cents per mile.

For the same application, if only the driver's labor cost is relevant, and that is assumed to be $3 per hour including fringe benefits, then, assuming an average speed of twenty miles per hour, there is an additional labor cost associated with each vehicle of 15 cents per mile.

Including these additional costs (and assuming seven year life for each vehicle) the per mile cost of transportation for the transport function is estimated to be 64.5 + 16.8 + 15.0 = 96 cents per mile for the year 1966.

APPENDIX H: A COMPUTER PROGRAM FOR GENERATING AND LISTING ALL ${}^{N}C_{K}$ COMBINATIONS

Let ${}^{N}C_{K}$ represent the number of combinations of the N consecutive integers 1, 2, 3, ..., N taken K at a time. SUBROUTINE COMB which was developed from Ref.26, is a Fortran computer program which can be used to generate any of the 2^N-1 possible combinations. The flow chart (SUBROUTINE COMB) for the generation of all the possible combinations is shown on Fig. H.1. The Fortran listing associated with the flow chart is included on Fig. H.2.

A sample computer output for N=10 is given in Figure H.3 where all the combinations for K=1, 2, 3 and 4 are shown. It is emphasized that a call to SUBROUTINE COMB with a particular choice for N and K returns to the user a single combination out of the total ${}^{N}C_{K}$ combinations available.

The input parameters required for using the subroutine are defined as follows:

- N - the number of integers over which the combinations are to be taken
- K - the length of the combinations where K can take on any of the values 1, 2, 3, ..., N
- JIN - the N consecutive integers representing the input over which combinations are to be taken are stored in the dimensioned variable JIN where JIN(1)=1, JIN(2)=2, ..., JIN(N)=N and $N \leq 20$
- JOUT - the output is stored in the dimensioned variable JOUT representing one of the ${}^{N}C_{K}$ total number of combinations. If the generated combination is of length K then the first number is stored in JOUT(1), the second in JOUT(2), ..., and finally the Kth

number in the combination is stored in JOUT(K) where $K \leq N$

ITST - a call to SUBROUTINE COMB results in the generation of one of the ${}^{N}C_{K}$ combinations which is subsequently stored in the output parameter [JOUT(I), I=1, 2, . . ., K]. However, in calling COMB one is faced with the problem of when all ${}^{N}C_{K}$ have been generated. The user should test ITST after each call to COMB. If ITST is 0, then further calls to the subroutine are required. If ITST=1, then all ${}^{N}C_{K}$ combinations have been generated previously and a new K should be specified. It should be emphasized that ITST must be initialized to 1 by the user in the call program at the start of the program, with SUBROUTINE COMB modifying ITST whenever necessary.

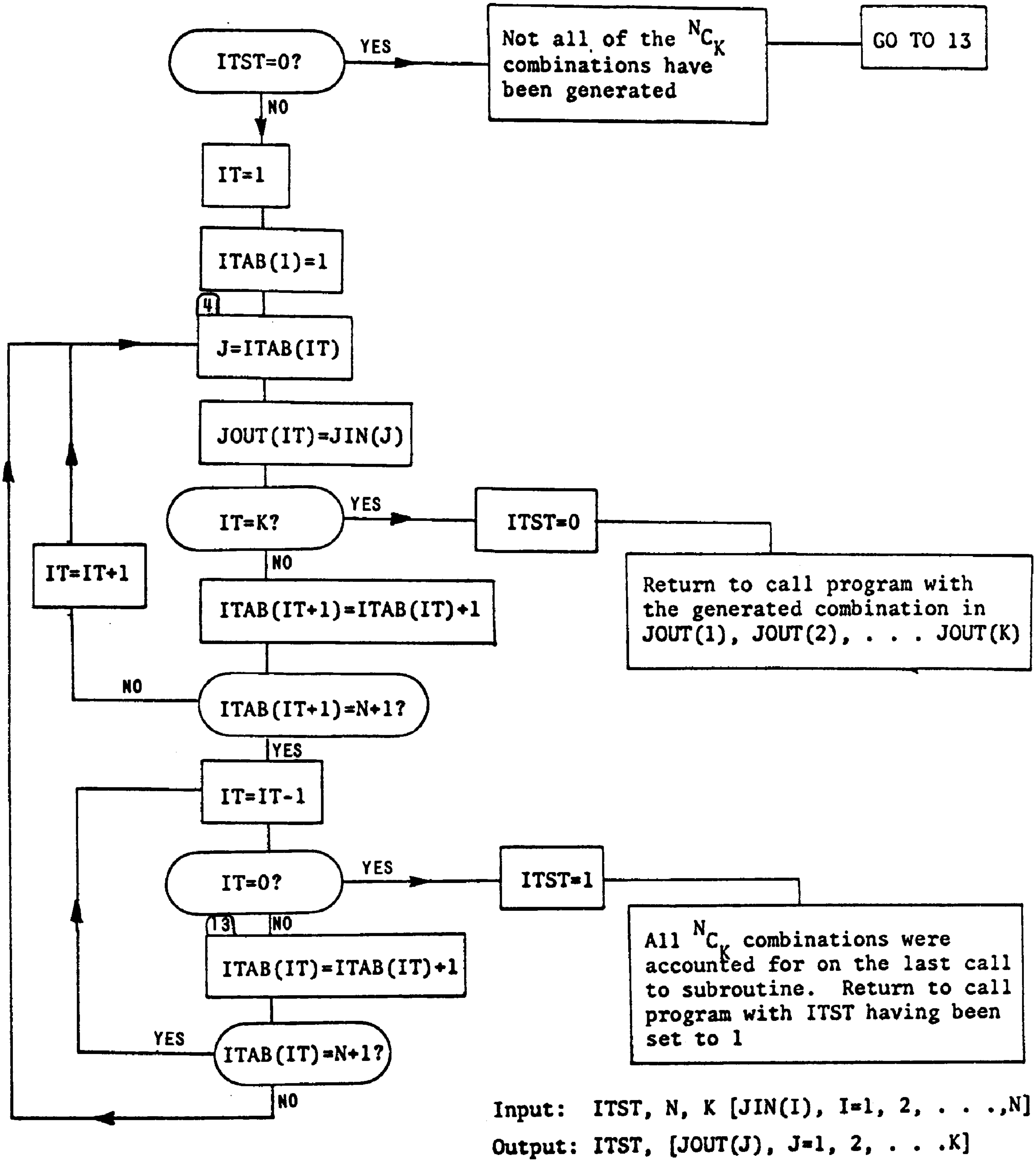


Figure H.1 FLOW CHART FOR SUBROUTINE COMB

```
      SUBROUTINE COMB
      COMMON/BOB/ ITST,N,K,JIN(20),JOUT(50),JOUTT(50),
     1            ITAB(50), DISTPD(20,20), DISTSF(200,20)
      IF(ITST .EQ.0) GO TO 13
    2 IT=1
    3 ITAB(1)=1
    4 J= ITAB(IT)
    5 JOUT(IT)= JIN(J)
    6 IF( IT.EQ. K ) GO TO 7
    8 ITAB( IT+1) = ITAB(IT) + 1
    9 IF(ITAB(IT+1).EQ.N+1) go to 10
   11 IT=IT+1
      GO TO 4
   10 IT=IT-1
   12 IF(IT.EQ.0) GO TO 20
   13 ITAB(IT)= ITAB(IT)+1
   15 IF ( ITAB(IT).EQ.N+1) GO TO 10
      GO TO 4
    7 ITST=0
      RETURN
   20 ITST=1
      RETURN
      END
```

Figure H.2 FORTRAN LISTING FOR SUBROUTINE COMB

K=1

1
2
3
4
5
6
7
8
9
10

K=2

1	2
1	3
1	4
1	5
1	6
1	7
1	8
1	9
1	10
2	3
2	4
2	5
2	6
2	7
2	8
2	9
2	10
3	4
3	5
3	6
3	7
3	8
3	9
3	10
4	5
4	6
4	7
4	8
4	9
4	10
5	6
5	7
5	8
5	9
5	10
6	7
6	8
6	9
6	10
7	8
7	9
7	10
8	9
8	10
9	10

K=3

1	2	3
1	2	4
1	2	5
1	2	6
1	2	7
1	2	8
1	2	9
1	2	10
1	3	4
1	3	5
1	3	6
1	3	7
1	3	8
1	3	9
1	3	10
1	4	5
1	4	6
1	4	7
1	4	8
1	4	9
1	4	10
1	5	6
1	5	7
1	5	8
1	5	9
1	5	10
1	6	7
1	6	8
1	6	9
1	6	10
1	7	8
1	7	9
1	7	10
1	8	9
1	8	10
1	9	10
2	3	4
2	3	5
2	3	6
2	3	7
2	3	8
2	3	9
2	3	10
2	4	5
2	4	6
2	4	7
2	4	8
2	4	9
2	4	10
2	5	6
2	5	7
2	5	8
2	5	9
2	5	10
2	6	7
2	6	8

Figure H.3 SAMPLE COMPUTER OUTPUT OF $^{10}C_K$ FOR K=1, 2, 3 AND 4

2	6	9
2	6	10
2	7	8
2	7	9
2	7	10
2	8	9
2	8	10
2	9	10
3	4	5
3	4	6
3	4	7
3	4	8
3	4	9
3	4	10
3	5	6
3	5	7
3	5	8
3	5	9
3	5	10
3	6	7
3	6	8
3	6	9
3	6	10
3	7	8
3	7	9
3	7	10
3	8	9
3	8	10
3	9	10
4	5	6
4	5	7
4	5	8
4	5	9
4	5	10
4	6	7
4	6	8
4	6	9
4	6	10
4	7	8
4	7	9
4	7	10
4	8	9
4	8	10
4	9	10
5	6	7
5	6	8
5	6	9
5	6	10
5	7	8
5	7	9
5	7	10
5	8	9
5	8	10
5	9	10
6	7	8
6	7	9
6	7	10

Figure H.3 SAMPLE COMPUTER OUTPUT OF $^{10}C_K$ FOR K=1, 2, 3 AND 4 (Cont.)

6	8	9	
6	8	10	
6	9	10	
7	8	9	
7	8	10	
7	9	10	
8	9	10	

K-4

1	2	3	4
1	2	3	5
1	2	3	6
1	2	3	7
1	2	3	8
1	2	3	9
1	2	3	10
1	2	4	5
1	2	4	6
1	2	4	7
1	2	4	8
1	2	4	9
1	2	4	10
1	2	5	6
1	2	5	7
1	2	5	8
1	2	5	9
1	2	5	10
1	2	6	7
1	2	6	8
1	2	6	9
1	2	6	10
1	2	7	8
1	2	7	9
1	2	7	10
1	2	8	9
1	2	8	10
1	2	9	10
1	3	4	5
1	3	4	6
1	3	4	7
1	3	4	8
1	3	4	9
1	3	4	10
1	3	5	6
1	3	5	7
1	3	5	8
1	3	5	9
1	3	5	10
1	3	6	7
1	3	6	8
1	3	6	9
1	3	6	10
1	3	7	8
1	3	7	9
1	3	7	10
1	3	8	9
1	3	8	10
1	3	9	10
1	4	5	6
1	4	5	7
1	4	5	8

Figure H.3 SAMPLE COMPUTER OUTPUT OF $^{10}C_K$ FOR K=1, 2, 3 AND 4 (Cont.)

1	4	5	9
1	4	5	10
1	4	6	7
1	4	6	8
1	4	6	9
1	4	6	10
1	4	7	8
1	4	7	9
1	4	7	10
1	4	8	9
1	4	8	10
1	4	9	10
1	5	6	7
1	5	6	8
1	5	6	9
1	5	6	10
1	5	7	8
1	5	7	9
1	5	7	10
1	5	8	9
1	5	8	10
1	5	9	10
1	6	7	8
1	6	7	9
1	6	7	10
1	6	8	9
1	6	8	10
1	6	9	10
1	7	8	9
1	7	8	10
1	7	9	10
1	8	9	10
2	3	4	5
2	3	4	6
2	3	4	7
2	3	4	8
2	3	4	9
2	3	4	10
2	3	5	6
2	3	5	7
2	3	5	8
2	3	5	9
2	3	5	10
2	3	6	7
2	3	6	8
2	3	6	9
2	3	6	10
2	3	7	8
2	3	7	9
2	3	7	10
2	3	8	9
2	3	8	10
2	3	9	10
2	4	5	6
2	4	5	7

Figure H.3 SAMPLE COMPUTER OUTPUT OF ${}^{10}C_K$ FOR K=1, 2, 3 AND 4 (Cont.)

2	4	5	8
2	4	5	9
2	4	5	10
2	4	6	7
2	4	6	8
2	4	6	9
2	4	6	10
2	4	7	8
2	4	7	9
2	4	7	10
2	4	8	9
2	4	8	10
2	4	9	10
2	5	6	7
2	5	6	8
2	5	6	9
2	5	6	10
2	5	7	8
2	5	7	9
2	5	7	10
2	5	8	9
2	5	8	10
2	5	9	10
2	6	7	8
2	6	7	9
2	6	7	10
2	6	8	9
2	6	8	10
2	6	9	10
2	7	8	9
2	7	8	10
2	7	9	10
2	8	9	10
3	4	5	6
3	4	5	7
3	4	5	8
3	4	5	9
3	4	5	10
3	4	6	7
3	4	6	8
3	4	6	9
3	4	6	10
3	4	7	8
3	4	7	9
3	4	7	10
3	4	8	9
3	4	8	10
3	4	9	10
3	5	6	7
3	5	6	8
3	5	6	9

Figure H.3 SAMPLE COMPUTER OUTPUT OF $^{10}C_K$ FOR K=1, 2, 3 AND 4 (Cont.)

3	5	6	10
3	5	7	8
3	5	7	9
3	5	7	10
3	5	8	9
3	5	8	10
3	5	9	10
3	6	7	8
3	6	7	9
3	6	7	10
3	6	8	9
3	6	8	10
3	6	9	10
3	7	8	9
3	7	8	10
3	7	9	10
3	8	9	10
4	5	6	7
4	5	6	8
4	5	6	9
4	5	6	10
4	5	7	8
4	5	7	9
4	5	7	10
4	5	8	9
4	5	8	10
4	5	9	10
4	6	7	8
4	6	7	9
4	6	7	10
4	6	8	9
4	6	8	10
4	6	9	10
4	7	8	9
4	7	8	10
4	7	9	10
4	8	9	10
5	6	7	8
5	6	7	9
5	6	7	10
5	6	8	9
5	6	8	10
5	6	9	10
5	7	8	9
5	7	8	10
5	7	9	10
5	8	9	10
6	7	8	9
6	7	8	10
6	7	9	10
6	8	9	10
7	8	9	10

Figure H.3 SAMPLE COMPUTER OUTPUT OF ${}^{10}C_K$ FOR K=1, 2, 3 AND 4 (Cont.)

APPENDIX I: LISTING AND SAMPLE OUTPUT OF THE FACILITY SELECTION MODEL

This Appendix contains a FORTRAN listing of the facility selection model described in Section 4.3. The listing appears in Fig. I.1.

A DO loop is set up so that a number NCASE of runs can be input at the same time. In the particular setup pictured in Fig. I.1, the sources are the same in all runs, as are the facility types and their locations. The only thing which changes from run to run are the specific parametric descriptors of the facilities.

The input deck for a series of runs of this type is as follows:

CARD 1: NCASE = number of cases

CARD 2: NS = number of sources

CARDS $3A_1$-$3A_{L(3)}$: (Q(I)) = source quantities [NS of them] eight to a card

CARDS $4A_1$-$4A_{L(4)}$ (XS(I), YS(I)) = source locations [NS pairs] four pairs to a card

CARD 5: N = number of facilities
NPP = number of processing plants
NDS = number of disposal sites

CARD 6: JIN(J) = facility names [N of them] eight to a card (Usually the first N integers are used)

CARDS $7A_1$-$7A_{L(7)}$: (XF(J), YF(J)) = facility locations [N of them] four pairs to a card.

This is followed by a set of N cards for each run, making NCASE x N cards in all. For each run, one card is required to describe each facility. Each processing plant card includes:

PFC = the A_j of the text

PCIN = the a_j of the text

PPC = the c_p of the text

PCOMP = the p_j of the text

PCTO = the c_T' of the text

PCTTPP = the c_T of the text

Each disposal site card includes

DFC = the A_j of the text

DCIN = the a_j of the text

DDC = the c_D of the text

DCOMP = a constant similar to p_j, not used in the text

DCTTDS = the c_T of the text

For specific formats, see the listing.

In Fig. I.2 is a portion of the output of one run of the program. In this run, five facilities were on trial, and what is shown is the minimum cost selection, namely all except Facility 5. The long list within the output gives the service area assignments for each of the 110 sources. The string of zeros in the other column indicates that there are no ties among possible facility assignments for any of the sources.

Figure I.1 FORTRAN LISTING OF FACILITY SELECTION MODEL

```
      COMMON/808/ ITST,N,K,JIN(20),JOUT(50),JOUTT(5C),
     1            ITAB(50), DISTPD(20,20), CISTSF(200,20)
      COMMON/COST/ PFC(20),PCIN(20),PPC(20),PCOMP(20),PCTO(20),PCTTPP(20
     1             ),CFC(20),DFCIN(20),CDC(20),DCOMP(20),DCTTDS(2C)
     2      ,C(20),Q(20C),JEQUAL(200),JPREQ(200)
     3  ,XS(200),YS(2C0),XF(2C),YF(20),AK(2C0,20)
     4 ,JTFMP(200),JPRINT(200)
      EPSL=.00CC1
      READ(5,5100) NCASE
      READ(5,5100) NS
 51C0 FORMAT(I1C)
      READ(5,10C1) (Q(I),I=1,NS)
      READ(5,1001) ( XS(I),YS(I),I=1,NS )
 1001 FORMAT( 8F10.0 )
      READ(5,100C)    N,NPP,NDS
      READ(5,100C) (JIN(I),I=1,N)
 1000 FORMAT( 8I1C )
      READ(5,1001) ( XF(I),YF(I),I=1, N )
      KNDS1= NDS + 1
      DO 5000   ICASE=1,NCASE
      IF(NPP.EQ.0) GO TO 2000
      READ(5,2001) (PFC(I),PCIN(I),PPC(I),PCOMP(I),PCTO(I),PCTTPP(I) ,
     1             I=KNDS1,N )
 2CC0 READ(5,2002) (DFC(I),DFCIN(I),DDC (I),CCOMP(I),DCTTDS(I),I=1,NDS  )
 2001 FORMAT(6F10.0)
 2002 FORMAT(5F10.0)
      DC 600 II=1,50
  600 JOUTT(II)=C
      DC 601 I=1,200
      JTEMP(I)= C
  6C1 JPRINT(I)= 0
      KOUT=0
      WRITE(6,5001)
 5001 FORMAT(1H1)
      WRITE(6,5002) ICASE
 5002 FORMAT(25X,'CASE NUMBER',I3,/////)
```

Figure I.1 FORTRAN LISTING OF FACILITY SELECTION MODEL (Cont.)

```
          WRITE(6,3000) (JIN(I),I=1,N)
     3000 FORMAT(  ' FACILITIES'  / 10I10 )
          WRITE(6,3001) (Q(I),I=1,NS)
     3001 FORMAT(  ' CUANTITIES' / (8E12.5))
          WRITE(6,1CC2) NS,N,NPP,NDS
     1002 FORMAT(' NOS OF SOURCES AND FACILITIES', 4I10,///)
          WRITE(6,1003) (XS(I),YS(I),I=1,NS )
     1C03 FORMAT('  SCURCE COORDINATES' / (5X, 4E15.5))
          WRITE(6,1C53) (XF(I),YF(I),I=1,N )
     1C53 FORMAT(' FACILITY CCCRDINATES'/ (5X,4E15.5))
          IF(NPP.EQ.0)  GO TO 2005
          WRITE(6,1004) (PFC(I),PCIN(I),PPC(I),PCOMP(I),PCTO(I),PCTTPP(I),
         1               I=KNDS1,N )
     1004 FORMAT('  PROCESSING PARAMETERS' / (5X,6E15.5))
     2005 WRITE(6,1054) (DFC(I),CFCIN(I),DDC(I),DCOMP(I),DCTTOS(I),I=1,NDS )
     1054 FORMAT('  DISPOSAL PARAMETERS' / (5X,5E15.5))
        1 AMIN= 10**20
          ITST= 1
          IF(NPP.EC.0) GO TO 2003
        2 DO 100 J2=1,NDS
          KK= NDS+1
          CO 100 J1= KK,N
      1C0 DISTPD(J1,J2) =  SQRT( ( XF(J1)-XF(J2))**2 + (YF(J1)-YF(J2))**2 )
     2003 DO 101 I1=1,NS
          DO 101 I2=1,N
      101 DISTSF(I1,I2)= SQRT( (XS(I1)-XF(I2))**2 + (YS(I1)- YF(I2))**2 )
        3 K=1
        5 ITST= 1
        6 DO 104 I=1,50
          JCUT(I)= 0
      104 ITAB(I)= 0
        4 CALL  COMB
C  JOUT(I)  I=1,2,3 --- K  CCMES BACK FROM COMB
        7 IF(ITST.EC.1) GC TC 4141
       11 IF( JOUT(1).GT.NDS ) GO TO 4
C JCUT HAS AT LEAST ONE CUMP SITE
C  BEGIN COMPUTATICN  OF  C(J)
```

Figure I.1 FORTRAN LISTING OF FACILITY SELECTION MODEL (Cont.)

```
   13 J=1
      JJ=0
  200 J1= JOUT(J)
  201 IF( J1.GT. NDS) GO TO 206
  202 JJ=JJ + 1
      BJ =  DCOMP(J1) * DDC(J1)
      C(J1) = DFCIN(J1) +  BJ
  203 IF(J.GE.K ) GO TO  14
  205 J=J+1
      GO TO 200
  206 J2=1
      BJ= 10**20
  207 J22= JOUT(J2)
      TEMP=   PCTC(J1)*DISTPD(J1,J22) +  DDC(J22) + DFCIN(J22)
      TEMP=   PCOMP(J1)* TEMP  +  PPC(J1)
  208 IF(TEMP.GE.BJ)  GO TO 209
  212 BJ= TEMP
  209 IF( J2.LT.JJ)  GO TO 210
  211 C(J1) =  PCIN(J1) +  BJ
      GO TO 203
  210 J2 = J2 + 1
      GO TO 207
   14 DO 300 I=1,NS
      DO 300 J=1,K
      J1= JOUT(J)
      IF(J1.GT.NDS) GO TO 301
      AK(I,J) =  C(J1)  +  DCTTDS(J1) *  DISTSF(I,J1)
      GO TO 300
  301 AK(I,J) =  C(J1)  +  PCTTPP(J1) *  DISTSF(I,J1)
  300 CONTINUE
   15 AKMIN = 10**20
  401 TMP=0
      DO 905 I=1,NS
  905 JEQUAL(I)= 0
  402 I=1
```

Figure I.1 FORTRAN LISTING OF FACILITY SELECTION MODEL (Cont.)

```
      4C3 J=1
          AKMIN=10**2C
      404 IF(AK(I,J).LT.AKMIN- EPSL) GO TO 405
      406 IF(J.GE.K ) GO TO 408
      4C7 J=J+1
          GC TO 404
      4C5 AKMIN = AK(I,J)
          JTEMP(I)= JOUT(J)
          JIND=J
          GO TO 406
      408 TMP = AKMIN* C(I) + TMP
          J3= JIND+1
          IF(J3.GT.K) GO TO 4C9
      903 TT= ABS( AK(I,J3) - AKMIN)
          IF( TT.LT. EPSL) JEQUAL(I) = 1
          IF(J3.GE.K) GO TO 409
          J3= J3+1
          GO TO 903
      409 IF(I.GE.NS) GO TO 411
      410 I=I+1
          GO TO 4C3
C  MIN  AK(I,J)  COMPUTED  AND IS LOCATED IN  TMP
      411 AMP=0
          DO 500 I=1,K
          J1= JOUT(I)
          IF( J1.GT. NDS) GC TC 501
          AMP= AMP+ DFC(J1)
          GO TO 500
      5C1 AMP=AMP + PFC(J1)
      500 CONTINUE
C   SUM AJ  CCMPLETEC  ANC  IS  IN  AMP
          TEMP = AMP + TMP
       16 IF(TEMP.GT.(AMIN+EPSL)) GO TO 4
          WRITE(6,5001)
          WRITE(6,999C) (JOLT(J1),J1=1,K)
     9990 FORMAT(//' THE FACILITIES BEING CONSIDERED ARE ',2CI4)
```

Figure I.1 FORTRAN LISTING OF FACILITY SELECTION MODEL (Cont.)

```
      DO 602 I=1,NS
      JPREQ(I)= JEQUAL(I)
  602 JPRINT(I)= JTEMP(I)
   17 AMIN= TEMP
      KOUT = K
      DC 700 J=1,K
  700 JOUTT(J)= JOUT(J)
      JJ=0
      J=1
  8C1 J1= JOUTT(J)
  8C2 IF( J1.GT. NDS) GO TC 8C7
  803 JJ = JJ + 1
  804 WRITE(6,850)  J1
  850 FORMAT( ' DISPOSAL SITE NUMBER =', I3  )
  805 IF(J.GE.K) GO TO 853
  8C6 J=J+1
      GO TO 801
  807 J2=1
  808 BJJ =10**20
  8C9 J22 = JOUTT(J2)
  810 TEMP= PCTO(J1)* DISTPD(J1,J22)  + DDC(J22)   + DFCIN(J22)
  811 IF(TEMP.LT.BJJ-EPSL) GC TC 812
  813 IF(J2.GE. JJ) GO TO 815
  814 J2= J2+ 1
      GO TO 809
  812 JDUMP = J22
      BJJ=TEMP
      GO TO 813
  815 WRITE(6,851) J1,JDUMP
  851 FORMAT( ' PROCESSING PLANT NO. =',I3,5X,'DISPOSAL SITE NO. =',I3 )
C   INSERT BLOCK A
  900 J2= JDUMP + 1
  902 IF(J2.GT.JJ) GC TC 805
      J22= JOUTT(J2)
      TEMP= PCTO(J1)* DISTPD(J1,J22)  + DDC(J22)   + DFCIN(J22)
      TMBJ= ABS( TEMP - BJJ       )
```

Figure I.1 FORTRAN LISTING OF FACILITY SELECTION MODEL (Cont.)

```
          IF( TMBJ.LT.EPSL) WRITE(6,851) J1,J22
          IF( J2.GE.JJ) GO TO 805
          J2= J2 + 1
          GO TO 902
      853 WRITE(6,904) AMIN
      904 FORMAT(' MINIMUM COST =', E12.6//)
          WRITE(6,852)  (I,JPRINT(I),JPREQ(I),I=1,NS)
      852 FORMAT(10X,'SOURCE NO.       FACILITY ASSIGNMENT        EQUALITY
         *TEST'/(I15,I20,I25))
          GO TO 4
     4141 IF(K.GE.N) GO TO 10
        9 K=K+1
          GO TO 5
       10 WRITE(6,5001)
          WRITE(6,9970)
     9970 FORMAT(60X,'COMPLETE COST MATRIX',///)
          DO 9981 I=1,NS
     9981 WRITE(6,9982)   (I,J,AK(I,J),J=1,N)
     9982 FORMAT(/,5(2X,I4,2X,I4,2X,E11.5))
     5000 CONTINUE
          STOP
          END
```

Figure I.2 SAMPLE OUTPUT OF FACILITY SELECTION MODEL

```
THE FACILITIES BEING CONSIDERED ARE     1   2   3   4
DISPOSAL SITE NUMBER =  1
DISPOSAL SITE NUMBER =  2
DISPOSAL SITE NUMBER =  3
PROCESSING PLANT NO. =  4      DISPOSAL SITE NO. =  1
MINIMUM COST =0.385422E 07
```

SOURCE NO.	FACILITY ASSIGNMENT	EQUALITY TEST
1	4	0
2	4	0
3	4	0
4	4	0
5	4	0
6	4	0
7	4	0
8	4	0
9	1	0
10	1	0
11	1	0
12	4	0
13	4	0
14	4	0
15	4	0
16	4	0
17	4	0
18	1	0
19	1	0
20	4	0
21	4	0
22	1	0
23	1	0
24	1	0
25	1	0
26	1	0
27	1	0
28	1	0
29	1	0
30	1	0
31	1	0
32	1	0
33	1	0
34	1	0
35	1	0
36	1	0
37	1	0
38	1	0

Figure I.2 SAMPLE OUTPUT OF FACILITY SELECTION MODEL (Cont.)

39	1	0
40	1	0
41	1	0
42	1	0
43	1	0
44	1	0
45	1	0
46	1	0
47	1	0
48	1	0
49	1	0
50	1	0
51	1	0
52	1	0
53	1	0
54	1	0
55	1	0
56	1	0
57	1	0
58	1	0
59	1	0
60	1	0
61	1	0
62	1	0
63	1	0
64	1	0
65	1	0
66	1	0
67	1	0
68	1	0
69	1	0
70	1	0
71	1	0
72	1	0
73	3	0
74	3	0
75	2	0
76	3	0
77	2	0
78	1	0
79	1	0
80	2	0
81	2	0
82	1	0
83	1	0
84	1	0
85	1	0

Figure I.2 SAMPLE OUTPUT OF FACILITY SELECTION MODEL (Cont.)

86	1	0
87	1	0
88	1	0
89	1	0
90	1	0
91	1	0
92	1	0
93	1	0
94	1	0
95	1	0
96	2	0
97	2	0
98	2	0
99	2	0
100	2	0
101	3	0
102	3	0
103	3	0
104	3	0
105	3	0
106	2	0
107	2	0
108	3	0
109	3	0
110	3	0

APPENDIX J ANALYSIS FOR FACILITY SELECTION OVER TIME

J.1 Assumptions

1. All initial introduction and subsequent expansion of processing plant capacity is maintained indefinitely into the future.

2. Both processing plant and disposal site costs are dichotomized into fixed and rate-dependent (or so-called "operating") costs.

3. For processing plants, fixed costs include mainly: initial capital outlay (if any), debt retirement, maintenance, and periodic major overhaul. Each capacity increment introduced at a time interval t_o will contribute a specified fixed cost schedule into the future which might appear as in Fig. J.1.

4. For disposal sites, fixed costs include initial capital outlay (if any) and debt retirement - these will be dependent on the specific site - initial capacity, location, etc. - and will be scheduled from time of initial activation of the site.

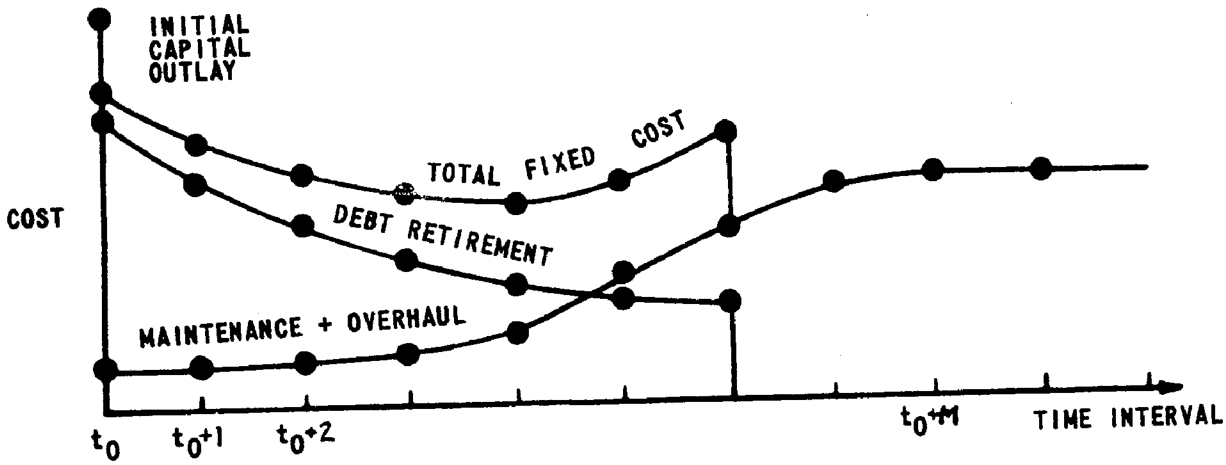


Figure J.1 PROJECTED FIXED COST SCHEDULE

5. For both processing plants and disposal sites, operating costs will be assumed to be proportional to current rate of operation.

6. Transportation costs are assumed to be proportional to quantity transported.

7. All dollars are adjusted to present levels, i.e., inflation is neglected; this seems to be the reasonable approach when combining costs over an extended time period.

8. Each processing plant has associated with it a specific, time-invariant volume reduction factor.

9. Each disposal site has associated with it two specific, time-invariant reduction factors, for unprocessed and processed material, respectively.

10. As in the static model, the quantity from any source area or the output from any processing plant is not permitted to be subdivided and goes to a single destination during each elemental time interval.

J.2 Input Parameters and Definitions

1. Total time period consists of T elemental intervals, each τ years in duration, and designated by variable $t = 1,2,\ldots,T$.

2. There are I source areas designated by $i = 1,\ldots,I$, with projected output q_{it} at time interval t. (All material levels are measured as cumulative total for a τ-year interval.)

3. There are N possible processing plants designated by $j=1,\ldots,N$, each with:

processing capacity: Q_{jt}; $t = 1-M, 2-M, \ldots, \mathcal{T}$*

actual processing level: $\bar{q}_{jt}$; $t = 1,\ldots,T$

reduction factor: r_j $(0 < r_j \leq 1)$

cost functions

fixed: $f_{jt} = \sum_{n=1}^{M} a_{jn} [Q_{j,t-n+1} - Q_{j,t-n}] + a_{j,M+1} Q_{j,t-M}$; $t = 1,\ldots,T$

operating: $g_{jt} = b_j \bar{q}_{jt}$

4. There are K possible disposal sites (sinks) designated by $k = 1,\ldots,K$ (and sometime by $j = N+1, N+2, \ldots, N+K$), each with:

initial capacity: V_k

prior-activation index: $\xi_k = \begin{cases} 0 & \text{; activation prior to } t=1 \\ T+1 & \text{; no activation prior to } t=1 \end{cases}$

time of activation: $t_k = 0,1,\ldots,T$

remaining capacity: V_{kt}; $t = 1,\ldots T$

actual operating level: v_{kt}; $t = 1,\ldots,T$

reduction factors

processed: r'_k $(0 < r'_k < 1)$

unprocessed: r''_k $(0 < r''_k < 1)$

cost functions

fixed: $f'_{kt} = C_{k,t-t_p}$ (=0 for $t < t_k$) ; $t = 1,\ldots,T$

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*Because of cost dependence on prior introduction of plant capacity out to M time intervals in the past (where M is number of time intervals in variable portion of fixed cost schedule), we require specification of $Q_{1-M}, Q_{2-M}, \ldots, Q_o$. The future capacities $Q_1,\ldots,Q_T$ will be determined as part of the solution.

operating: $q'_{kt} = d_k \, v_{kt}$; $t = 1,\ldots,T$

(V_k, V_{kt}, v_{kt} measured in units after reduction.)

5. Transportation costs from i^{th} source to j^{th} destination ($j=1,\ldots,N+K$) per unit load: S_{ij},
from j^{th} processed plant ($j=1,\ldots,N$) to k^{th} disposal site ($k=1,\ldots,K$) per unit load: T_{jk}.

6. Allocation variables (representing control variables for optimization):

$$X_{ijt} = \begin{cases} 0; i^{th} \text{ source not sent to } j^{th} \text{ p.p. or d.s. at time } t \\ 1; i^{th} \text{ source sent to " " " " " " "} \end{cases} \quad \begin{matrix} i=1,\ldots M \\ j=1,\ldots N+K \end{matrix}$$

$$Y_{jkt} = \begin{cases} 0; j^{th} \text{ p.p. not sent to } k^{th} \text{ d.s. at time } t \\ 1; j^{th} \text{ p.p. sent " " " " " "} \end{cases} \quad \begin{matrix} j=1,\ldots,N \\ k=1,\ldots,K \\ t+1,\ldots,T \end{matrix}$$

7. Projected population of region under service:
P_t ; $t=1,\ldots,T$

8. Derived quantities:
Actual processing level at j^{th} p.p. at time t:

$$q_{st} = \sum_{i=1}^{I} q_{it} \, x_{ijt}$$

Actual operating level at k^{th} site at time t:

$$v_{kt} = \left(\sum_{i=1}^{I} q_{it} \, x_{i,N+k,t} \right) r''_k + \left(\sum_{j=1}^{N} \bar{q}_{jt} \, r_j \, y_{jkt} \right) r'_k$$

Time of activation of k^{th} disposal site
$t_k = \min \left\{ \xi_k ; \; t \text{ such that } v_{kt} > 0 \right\}$

Total fixed cost at time t:

$$F_t = \sum_{j=1}^{N} f_{jt} + \sum_{k=1}^{K} f'_{kt}$$

Total operating cost at time t

$$G_t = \sum_{j=1}^{N} g_{jt} + \sum_{k=1}^{K} q'_{kt} + \sum_{i=1}^{I} \sum_{j=1}^{N+K} s_{ij}\, q_{it}\, x_{ijt}$$

$$+ \sum_{k=1}^{K} \sum_{j=1}^{N} T_{jk}\, \bar{q}_{jt}\, r_j\, y_{jkt}$$

J.3 Conditions for Solution

1. Constraints for Step 2 optimization (sequentially for each t = 1,...,T):

$$\sum_{j=1}^{N+K} x_{ijt} \equiv 1 \quad ; \quad i = 1,\ldots,I$$

$$\sum_{k=1}^{K} y_{jkt} \equiv 1 \quad ; \quad j = 1,\ldots,N$$

$$\left.\begin{array}{ll} \bar{q}_{jt} \leq Q_{jt} & ; \\ Q_{j,t+1} \geq Q_{jt} & ; \end{array}\right\} j = 1,\ldots,N$$

$$\left.\begin{array}{l} V_{k,1} = V_k \\ V_{k,t+1} = V_{kt} - v_{kt} \\ V_{kt} \geq v_{kt} \end{array}\right\} k=1,\ldots,K$$

2. Objective function for Step 2 optimization:

$$H_t = F_t + G_t$$

Minimize H_t over $\{ x_{ijt}, y_{jkt}, Q_{jt} \}$ sequentially for each

t = 1,2,...,T subject to the above constraints

3. Objective function for Step 4 optimization

$$h = \sum_{t=1}^{T} [H_t / P_t]$$

Minimize h over all permissible variations (subject to above Q and V constraints) in the times of destination changes for source area quantities and processing plant outputs, maintaining these times of destination changes in original semi-strict order corresponding to the Step 2 optimum solution. In this process x_{ijt} and y_{jkt} follow automatically and continue to satisfy constraints; Q_{jt} will likely require readjustment.