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Solid Waste and Remote Sensing*

Preliminary and studies suggest that small-scale aerial remote-sensing records and, in particular, aerial photographs can contribute to regional solid-waste management and planning.

INTRODUCTION

INCREASING population growth has accelerated the generation of solid wastes. At the same time available land suitable for proper waste disposal has decreased, and the search has begun for more efficient waste disposal methods. Concern for environmental degradation has increased the need for a better understanding of disposal site suitability. The collection, transportation and disposal of solid wastes increasingly crosses jurisdictional boundaries and suggests regional solutions to solid waste problems must be found. To approach this problem at the regional level, data are needed related to: (1) the quantity of solid wastes generated, (2) the characteristics of those wastes, and (3) satisfactory disposal sites/methods.

ABSTRACT: *In order to implement practical solid-waste planning and management at the regional level, data acquisition systems which are unrestricted by jurisdictional boundaries are needed. High-altitude aircraft remote sensing provides a regional working data base and information including waste distributions, waste characteristics, and quantities. Solid-waste quantities for a given area can be estimated from high-altitude aircraft photographs providing collateral statistics such as average amount of waste generated by a waste source unit, e.g., residential dwellings, commercial or industrial facilities or by population are available. Interpretation of high-altitude aircraft remote-sensing records provides essential data for solid-waste planners including the location of waste disposal sites and facilities and contributes toward selecting the most suitable disposal method or methods for a given region.*

That remote sensing can provide useful solid-waste management and planning data at the regional level is suggested by the authors' studies. Natural color and color-infrared aerial photography at scales from 1:12,000 to 1:120,000 were analyzed and applied to: (1) estimates of waste characteristics and quantities, (2) waste disposal site selection and utilization, (3) waste collection and transportation, (4) environmental impact of on-site and off-site disposal, and (5) location and identification of waste generating souces.

This paper examines existing techniques for acquiring statistical data for solid-waste management and addresses remote-sensing applications to estimates of solid-waste characteristics, distributions and quantities in the Tampa, Florida, area. It is anticipated that this preliminary work will be extended under NASA's ERTS-B program.

SOLID-WASTE ESTIMATION TECHNIQUES

Accurate data on quantities of solid waste generated for the nation or regions are often unavailable despite the use of national averages, field surveys, prediction models and waste multipliers. For purposes of this preliminary report, each technique will be ad-

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dressed separately with a view toward selecting suitable techniques for incorporation into a solid-waste quantity prediction and estimation system, which utilizes remote-sensing data.

NATIONAL AVERAGE TECHNIQUE

It has been estimated that the national average of waste generated per capita per day is 4.56 pounds (Table 1)†. Within urban areas the average is 5.92 pounds/capita/day, whereas in rural areas the average is 3.70 pounds/capita/day. Applying factors in Table 1 to the Tampa, Florida, area, a solid-waste characteristic and quantity profile for Tampa (based on present population of 277,767) would approximate the data presented in Table 2.

FIELD SURVEY TECHNIQUE

A 1968 national survey[1] of 6,259 communities (for an estimated 1967 population of 92,539,674 persons) was completed to determine community solid-waste practices in the United States. The nine regions of the Department of Health, Education and Welfare (including Region IV composed of Florida, Alabama, Georgia, Mississippi, South Carolina and Tennessee) were analyzed.

Measured or estimated quantities of community solid wastes collected annually were studied. Waste categories for which information was gathered included: (1) household, (2) commercial, (3) combined household and commercial, (4) industrial, (5) agricultural, (6) institutional, (7) demolition and construction, (8) street and alley, (9) tree and landscape, (10) park and beach, (11) catch basin, and (12) sewage treatment plant solids and pumping station cleanings. Waste quantities computed (Table 3) using field survey techniques vary greatly by region due to variables including: (1) the size of the population sampled per region; and (2) the physical and cultural characteristics of the regions themselves. State value judgements assigned to data quality provided a further

TABLE 1. AVERAGE SOLID WASTE GENERATED (WASTE FACTORS) BY WASTE CATEGORY (POUNDS/CAPITA/DAY)

Solid Wastes	*Urban Waste Factors*	*Rural Waste Factors*	*National Waste Factors*
Household	1.91	1.67*	1.91
Commercial	0.92	0.30*	0.91
Combined	2.40	3.28	2.64
Industrial	1.40	0.94	1.40
Demolition, Construction	0.47	0.07*	0.47
Street and Alley	0.19	0.01	0.19
Miscellaneous	1.03	.81	0.97
Totals	8.32	7.08	7.20

* Determined through average of estimated and measured waste Source: *Preliminary Data Analysis;* 1968 National Survey of Community Solid Waste Practices. U.S. Department of Health, Education and Welfare.

TABLE 2. ESTIMATED SOLID-WASTE QUANTITIES FOR TAMPA, FLORIDA (TONS/DAY) BASED ON NATIONAL AVERAGES APPLIED TO TAMPA'S POPULATION (277,767)

	TAMPA, FLORIDA SOLID WASTE ESTIMATE	
Solid Waste Category	*Based on Urban Waste Factors*	*Based on National Waste Factors*
Household	265	265
Commercial	128	128
Combined	333	366
Industrial	194	194
Demolition, Construction	65	65
Street and Alley	26	26
Miscellaneous	143	135
Total	1,154 (421,210 Tons/Yr.)	1,179 (431,000 Tons/Yr.)

Waste Factors Adopted from 1968 National Survey of Community Solid-Waste Practices Preliminary Report.

† This figure represents the total given in Table 1 minus the combined household/commercial waste category. Household and commercial wastes are represented in separate categories.

TABLE 3. ANNUAL MEASURED MEAN TONS OF SOLID WASTE/1000 POPULATION
(Region IV Includes Florida)

	National	*Region I*	*Region II*	*Region III*	*Region IV*	*Region V*
Household Refuse	350.76	339.93	372.02	151.96	259.80	239.65
Commercial Refuse	167.78	148.11	159.46	184.29	120.84	284.02
Comm/Household	482.04	1,685.75	425.92	552.18	520.27	379.69
Industrial	256.89	50.74	171.87	19.08	21.60	*
Agricultural	*	*	*	*	*	*
Institutional	41.70	*	145.91	*	21.60	*
Demolition/ Construction	87.85	377.25	67.90	*	*	*
Street & Alley Cleanings	35.09	73.48	37.54	21.38	*	3.710
Tree & Landscaping Refuse	3.38	128.00	2.37	*	*	*
Park and Beach Refuse	.988	*	.167	*	*	2.84
Catch Basin Refuse	24.68	*	2.15	*	*	*
Sewage Treatment Plant	110.83	*	47.28	20.98	*	141.15

* Insufficient Data; only estimates available.
Region I—Conn., Me., Mass., N.H., R.I., Vermont,
Region II—Delaware, N.J., N.Y., Penn.,
Region III—Kentucky, Md., N.C., Va., W.Va., D.C., Virgin Islands,
Region IV—Ala., Fla., Ga., Miss., S.C., Tenn.,
Region V—Ill., Ind., Mich., Ohio, Wisc.
Source: *Preliminary Data Analysis;* 1968 National Survey of Community Solid Waste Practices by Muhich, Klee and Britton for U.S. Dept. of HEW, Public Health Service; 1968. 483 pp.

indication as to why discrepancies occurred. Only 6.3 percent of the states reported that data was of *good* quality, 37.5 percent reported it to be of *fair* quality, and 56.2 percent reported it to be of *poor* quality. Based on the 8.3 percent of Florida's population that was surveyed, and comparing Region IV data for Tampa with national data, Table 4 demonstrates the complexity of predicting accurate solid wastes quantities for comparing gross national averages of solid wastes with relatively *individualized* regional waste quantities.

Some local, highly individualized survey studies have been completed by the Environmental Protection Agency's Bureau of Solid Waste Management. One of these studies[2] investigates quantities of solid waste generated in a residential low-income area of Cincinnati, Ohio. This report states that variations in the generation of solid wastes make it extremely difficult to predict quantities that can be expected from a dwelling within a low-income residential neighborhood. Influencing factors include climate, season, socioeconomic level, and dweller density. Although this study concluded (among other things) that the total number of occupants, not the dwelling type determined the total quantity of solid waste generated, this result is expected in low-income residential areas, due to overcrowding, but would not necessarily be true for other residential areas.

PREDICTION MODELS

A variety of prediction models for estimating waste quantity and characteristics exist. A prediction model[3] developed by the URS Research Company for the federal solid-waste management program "estimates and predicts on the basis of knowledge of materials and quantities before they become part of the solid waste stream, together with an understanding of the process by which materials become solid waste." This model relies on Bureau of Census and other data for predict-

TABLE 4. MEAN ANNUAL TONS OF SOLID WASTE FOR TAMPA, FLORIDA
Table based on a field survey technique with averages applied to Tampa's population (277,767)[1]

Type of Refuse	*Based on National Survey Data*	*Based on Region IV Data*
Household Refuse	97,000	71,965
Commercial Refuse	47,000	33,473
Comm./Household	133,000	144,000
Industrial	71,000	5,983[2]
Demolition/Construction	24,000	Insufficient Data
Street and Alley Cleanings	9,500	Insufficient Data
Tree and Landscape	833	Insufficient Data
Park and Beach	250	Insufficient Data
Catch Basin	6,500	Insufficient Data
Sewage Treatment Plant	30,600	Insufficient Data
Agricultural	Insufficient Data	Insufficient Data
Institutional	11,400	5,983
Grand Total	431,000	261,519[3]

[1] These quantities were computed based on measured mean tons of waste generated per thousand population surveyed for each category as listed in the *Preliminary Data Analysis* of the 1968 National Survey of Community Solid Waste Practices.

[2] The large variance between this figure and the National figure could be the result of the difference in sample size between the two. Although 2,697 communities were sampled at the National level, only 51 were sampled in Region IV for this category of wastes.

[3] A possible cause of statistical differences between Region IV and National Survey Data is the lack of data ("insufficient data") for some refuse-types.

TABLE 5. WASTE MULTIPLIERS
Developed for Santa Clara County, California

Residential	
Single Family Dwelling	1.43 tons/dwelling/year
Multiple Family Dwelling	0.66 tons/dwelling/year
Commercial and Public Facilities	3.81 tons/employee/year
Demolition and Construction	41.3 tons/employee/year
Industrial	
Ordnance and Accessories	0.658 tons/employee/year
Canning and Preserving	5.565 tons/employee/year
Other Food Processing	4.816 tons/employee/year
Tobacco	2.493 tons/employee/year
Textiles	0.525 tons/employee/year
Apparel	0.525 tons/employee/year
Lumber and Wood Products	21.688 tons/employee/year
Furniture and Fixtures	20.155 tons/employee/year
Paper and Allied Products	12.538 tons/employee/year
Printing, Publishing, Allied	13.202 tons/employee/year
Chemicals and Allied	8.210 tons/employee/year
Petroleum Refining	Omitted
Rubber and Plastics	1.548 tons/employee/year
Leather	2.493 tons/employee/year
Stone, Clay, Glass, Concrete	18.114 tons/employee/year
Primary Metals	6.730 tons/employee/year
Fabricated Metal Products	6.730 tons/employee/year
Nonelectrical Machinery	4.182 tons/employee/year
Electrical Machinery	2.978 tons/employee/year
Transportation Equipment	3.393 tons/employee/year
Instruments	2.517 tons/employee/year
Miscellaneous Manufacturing	2.493 tons/employee/year

SOURCE: *Comprehensive Studies of Solid Waste Management;* Second Annual Report; U.S. Dept. of H.E.W. Bureau of Solid Waste Management, 1970.

ing consumption habits in residential areas. Besides data on the consumption habits within a community, however, models must rely on information including: (1) population, (2) population density, (3) average size of household, (4) distribution of income, (5) number, size and type of establishments (wholesale and retail trade, selected services, manufacturers, mineral industries, and agriculture). Using the model, waste characteristics as well as quantities may then be estimated for a community.

WASTE MULTIPLIERS

A waste multiplier is a numerical estimation of the average quantity of waste generated by a waste source, resident or employee per unit of time. One report lists a two-step aproach for estimating waste quantities using waste multipliers[4]: (1) waste source units are expressed either as number of units, or by level of activity represented either by employment or local use and, (2) quantities of solid wastes are calculated as the product of the waste multiplier and source units. Waste multipliers can be developed for residential, commercial, non-manufacturing and public agencies, industrial, and agricultural sources of wastes. For example, a sample survey was completed in Santa Clara County, California, in order to develop waste multipliers and,

TABLE 6. COMPARISON OF SOLID-WASTE QUANTITY DATA GENERATED USING NATIONAL AVERAGE ESTIMATES, REGIONAL SURVEY AND WASTE MULTIPLIER TECHNIQUES AS APPLIED TO TAMPA, FLORIDA (TONS/YEAR)

Waste Source	*National Average Estimates*	*Direct Survey Region IV (Measure)*	*Waste Multipliers (Santa Clara Study)*
Single Family Dwelling	97,000[A]	72,000[E]	107,250[I]
Multiple Family Dwelling			15,000[J]
Total Household (includes household fraction of combined household/commercial wastes)	190,000[B]	172,000[F]	122,250
Commercial and Public Facilities (includes commercial fraction of combined household/commercial wastes)	87,000[C]	76,000[G]	190,000[K]
Industrial	71,000[D]	24,000[H]	114,000[L]
Canning and Preserving	*	*	25,000
Other Food Processing	*	*	
Tobacco	*	*	4,300
Printing, Publishing Allied	*	*	13,000
Chemicals and Allied	*	*	17,000
Stone, Clay, Glass, Concrete	*	*	24,000
Fabricated Metals	*	*	15,000
Miscellaneous Manufacturing	*	*	15,500
Grand Total	348,000	272,000	426,250

[A] Based on National Average for Household Wastes at 1.91 pounds/capita/day and Tampa Population of 277,767.

[B] Estimated 70% of combined household/commercial wastes as household.

[C] Estimated 30% of combined household/commercial wastes as commercial.

[D] Based on National Average for Industrial Wastes at 1.40 pounds/capita/day.

* No data Available.

[E] Based on Region IV Average for Household Wastes at 1.41 pounds/capita/day.

[F] Estimated 70% of Region IV combined household/commercial wastes as household.

[G] Estimated 30% of Region IV combined household/commercial wastes as commercial.

[H] Insufficient data was available for measured quantities. Estimated quantities from Region IV survey were used.

[I] Based on waste multiplier of 1.43 tons/dwelling/year for single family dwellings.

[J] Based on waste multiplier of 0.66 tons/dwelling/year for multiple family dwellings.

[K] Retail, wholesale, selected services, banks, hospitals and city government at 50,000 employees and 3.81 tons/employee/year.

[L] Based on waste multipliers in Table 5.

finally, to compute the average quantities of waste generated for each waste source. Waste multipliers are summarized in Table 5.

To determine the numerical correlation between solid waste quantity data generated by waste multipliers, national waste averages and direct survey, Santa Clara County waste multipliers were applied to Tampa, Florida. Climatic and broad population similarities made use of California statistics reasonable for this purpose. Table 6 reveals obvious discrepancies between waste quantities estimated using

FIG. 1. A black-and-white reproduction of a 1:120,000-scale color-infrared photograph. Two photographs were spliced together in order to center on the city of Tampa, Florida. Through interpretation of this photograph the city was divided into 10 waste source areas. Number of buildings within each waste source area and the areal size of each area was then computed. Using available waste multipliers, estimates of solid waste quantities for each waste source area were made. Waste multipliers assigned an average quantity of waste per unit of time to each waste source unit, e.g., tons of waste generated per single-family dwelling per year.

different methods. National waste averages, direct regional survey, and waste multipliers all yield different answers for the same area. Waste multipliers which pertain specifically to Santa Clara County, California, upon application to Tampa, Florida, or to any other area would yield more detailed information on waste characteristics for specific industries than previously cited methods. Waste multipliers, of course are developed from a direct analysis of waste generated by specific types of industry.

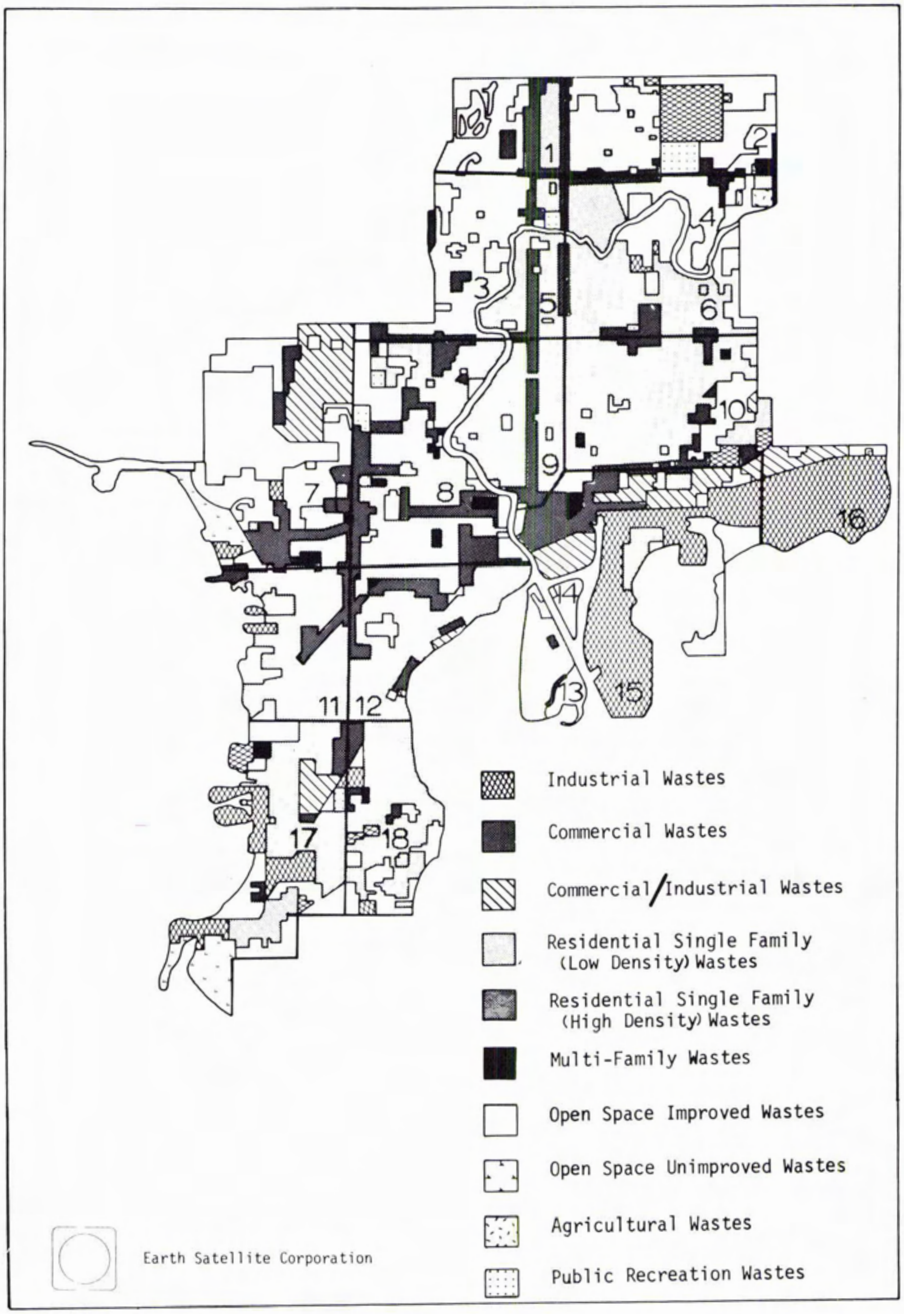

FIG. 2. Solid waste quantities, characteristics and distributions in Tampa, Florida. (To be used in conjunction with Table 7.)

Role of Remote Sensing

Urban land-use studies using high-altitude aircraft photographs are actively being conducted by several federal agencies, but they have not been applied to solid-waste problems. With 1:120,000 scale photographs and a 9 × 9-inch photo format, approximately 325 square miles of the earth's surface may be inventoried in a single frame. Such aerial photographs can be used to compute the quantities of waste generated in a given area. Wastes have been traditionally grouped into general categories which correspond to: (1) household, (2) commercial, (3) industrial, and (4) agricultural refuse categories. Information on the areal size of each of the refuse categories and their spatial distribution can be easily extracted by experienced analysts from high-altitude aerial photographs. Detailed information within these categories can be obtained. For example, it is possible to separate single-family from multiple-family dwellings, and to distinguish between low- and high-income residential areas. In agricultural areas, crop types may be identified; within industrial areas, specific types of industry can often be identified.

Because solid-waste collection, transportation and disposal is now a regional problem, high-altitude aerial photographs (which cross the restrictions imposed by jurisdictional boundaries) in effect provides a regional working data base.

A special advantage of small-scale, remote-sensing records is that they permit a rapid assessment of the spatial distribution of each refuse category. Little difficulty has been encountered in identifying refuse (solid waste) categories in the Tampa, Florida, test area, or in describing the general characteristics which are associated with each category.

A primary difficulty has been the unavailability of accurate waste quantity data. Considerable effort has been directed to describing present techniques used for estimating waste quantities, and to select the best method for incorporation into a remote-sensing/solid-waste quantity estimation model. National waste averages, direct survey techniques, and waste multipliers are largely based on unit weight or volume generated per resident or per employee. Waste multipliers can also be adapted to waste sources, i.e., can be used to estimate quantities of waste generated by, e.g., single family or multiple family dwellings or agricultural wastes based on field acreage.

Waste multipliers which are based on some form of spot sampling-survey can best be incorporated into a solid-waste quantity estimation/remote-sensing system. Additional surveys such as the one completed for Santa Clara County, California, should be conducted in order to establish meaningful regional, rather than national, waste multipliers. This will facilitate solid waste studies using small-scale imagery.

Estimates of Waste Quantities in Tampa, Florida

Using high-altitude 1:120,000-scale color-infrared photographs (Figure 1), the waste characteristics, distributions, and quantities for Tampa, Florida, were computed. Waste multipliers were applied to the study area experimentally to test a procedure for future applications of remote sensing to solid-waste quantity estimation. Tampa was separated into ten solid waste source areas (Figure 2) using the 1:120,000 scale photographs. An inventory of the number of buildings within each source area was then completed. In order to simplify computations, an 18-section grid was added to the photograph, and building tabulations were made for each grid (Table 7). Based on the building type and average occupance per unit (1970 Bureau of Census data for Tampa), the number of residents per dwelling and employees per industry have been estimated. Existing waste multipliers were then applied to these figures with the results listed in Table 8.

Although industry subcategories were not singled out for individual computation (principally due to the resolution constraints of the imagery), some types of industrial activity (refining, mining, storage, etc.) could be identified; in conjunction with complementary 1:60,000-scale photographs, detailed waste quantity estimates within industrial areas could be made. (Large-scale photographs will also be tested to estimate floor space and hence estimated number of employees for many industries.)

Agricultural wastes for Tampa were negligible. The Santa Clara study, however, did develop waste multipliers for agriculture and these could easily be developed for other regional areas. (For example, waste multipliers for vineyards and orchards were developed.)

Open space and public recreation area size was calculated, but information on area visitation was necessary in order to estimate waste quantities. Experimental computations to extract these data will be conducted at a later date.

TABLE 7. NUMBER OF BUILDINGS AND TOTAL LAND AREA FOR EACH WASTE CATEGORY IN TAMPA, FLORIDA

Waste Category	*GRID NUMBER* 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	*Total Number of Bldg.*	*Total Number of Sq. Mi.*
Industrial Wastes	0	9	0	0	0	0	50	0	0	20	20	10	0	7	300	50	50	20	543	11
Commercial Wastes	250	350	250	150	350	350	500	650	350	250	350	650	150	0	700	0	150	150	5700	12
Comm. Industrial Wastes	0	0	0	0	0	10	100	0	50	50	100	50	0	0	150	50	20	50	630	4
Residential Single Family (High Density) Wastes	1000	1500	1000	2000	0	1500	1500	1000	1000	1000	1500	1000	1500	0	1000	1000	2000	2000	21500	6
Residential Single Family (Low Density) Wastes	2500	3000	3500	4000	3000	4000	2000	5000	3000	5000	4000	5000	1000	0	3000	0	3000	2000	53000	27
Residential Multi Family Wastes	0	10	0	2	0	0	5	20	20	10	0	20	10	0	10	0	10	20	147	4
Open Space Improved Wastes, Sq. Mi.	0.1	1.5	0.5	0.5	0.1	2.5	2.4	2.0	0.1	0.1	2.0	1.0	0.1	0.3	0.5	0.1	0.1	0.1	N/A	14
Open Space Unimproved Wastes, Sq. Mi.	0	0	0	0.5	0	0	0.5	0	0	0	0	0	0	0	0	0	0.1	0	N/A	2
Agricultural Wastes, Sq. Mi.	0	0.10	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A	1
Public Recreational Wastes	0	5	4	0	0	5	5	10	0	0	0	10	1	0	5	0	2	5	53	4
Total City of Tampa																			81573	85

TABLE 8. ESTIMATION OF SOLID-WASTE QUANTITIES IN TAMPA, FLORIDA USING REMOTE-SENSING METHODS AND SOLID-WASTE MULTIPLIERS

Waste Categories	*Number of Buildings*	*Number of Residents*	*Number of Employees*	*Waste Multiplier*	*Tons/Year Total Solid Wastes*
Industrial	545	N/A	16,000	6.74 tons/ employee year	107,000
Commercial	5,200	N/A	46,000	3.81 tons/ employee year	175,000
Commercial/ Industrial	530/100	N/A	4200/3000	6.74/3.81	28,308/11,430
Single Family Dwellings (Low Density)	75,000	195,000 @2.6 persons/ residence	N/A	1.43 tons/ unit/year	107,250
Single Family Dwellings (High Density)					
Multi-Family Dwellings	147 bldgs. / 22,639 Units	40,750 @1.8 persons/ residence	N/A	0.66 tons/ unit/year	15,000
Open Space Improved	N/A	N/A	N/A	N/A	*
Open Space Unimproved	N/A	N/A	N/A	N/A	*
Agricultural	N/A	N/A	N/A	N/A	*
Public Recreation	N/A	N/A	N/A	N/A	*

Note: Average number of employees per industrial or commercial unit based on decennial census data.

A study by the Environmental Protection Agency indicates that wastes generated at swimming beaches, picnic areas, and observation sites vary from .04 to .93 pounds/visitor/day.[5] Considering such variability, recreational waste multipliers based on area estimates from small-scale aerial photographs would be subject to errors. It is judged that high-altitude aerial photographs must be supplemented by large-scale aerial or field observations to ensure accurate recreational waste estimates. (Large-scale photographs can serve, for example, to estimate visitors based on number of cars in parking areas. Light-aircraft observation could also serve as a visitor sampling method.)

Demolition and construction within the city limits of Tampa was negligible. Large-scale building operations on the outskirts of the city could be easily identified on the 1:120,000-scale color-infrared photographs. Although waste multipliers were developed in the Santa Clara study for this waste category, they are based on number of pounds generated per construction or demolition worker and cannot be used to estimate waste quantity based on the size of the construction or demolition project. The use of supplementary large scale photography is required.

Figure 3 shows urban expansion in Tampa. New urban and industrial development add to the solid waste stream, and occupy land suitable for waste disposal. Comparative 1:120,000-scale aerial photographic coverage has proven useful for identifying changes within waste generating source areas, new development (urban or industrial), the replacement of one category of wastes with another (e.g., residential for agricultural) and discriminating the direction of growth of waste source areas. Changing waste quantities, characteristics, and distributions may, therefore, also be estimated. This is essential information for implementing solid waste planning programs (including budgeting) at the regional level.

A variety of other experimental applications of remote sensing to solid waste man-

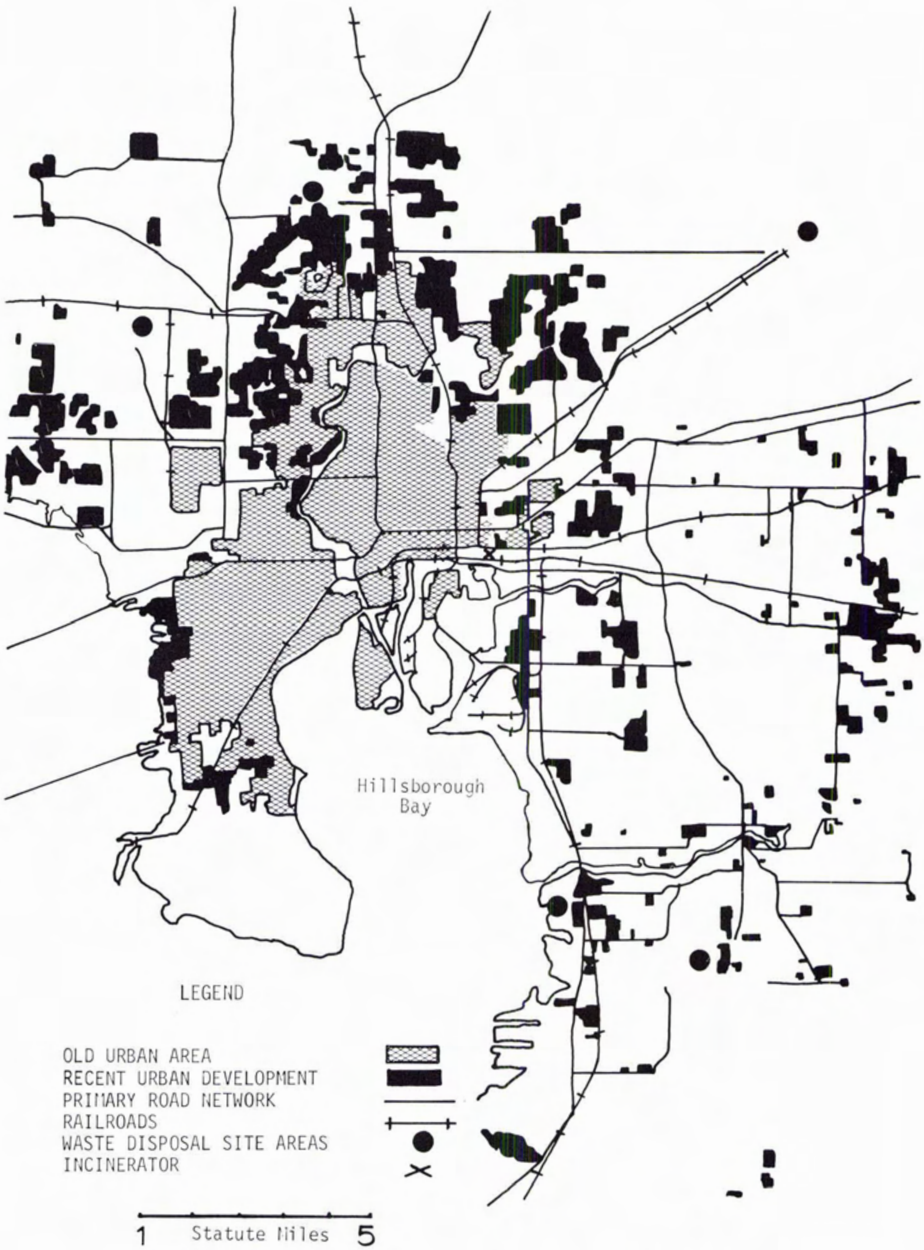

FIG. 3. Urban growth in Tampa, Florida, metropolitan area.

agement problems are being tested. Selected applications are listed in Table 9.

Summary and Conclusions

This paper reports on the early results of a research program to explore the utility of aerial remote sensing techniques for solid-waste management and planning. The results obtained to date are encouraging but require additional testing in cooperation with solid-waste management groups.

Table 9. Applications of Remote Sensing to Solid-Waste Management and Planning*

Solid-Waste Applications	*Remote-Sensing Record*	*Remote-Sensor Platform Used*	*Remote Sensor Applications (Preliminary)*
Waste Quantities, Characteristics, and Distributions	Color-Infrared Photographs 1:120,000 Scale (Note: Color-IR is Preferred Over Natural Color Photographs at High Altitude Due to Better Building/Vegetation Contrasts and Color-IR's Haze Penetration Capability)	High-Altitude Aircraft	• Solid-waste source areas—industry, commercial, residential, open space, recreational and agricultural can be delineated. • Spatial distribution of solid-waste source areas can be shown. • An inventory of buildings (type and number) can be made. • Area size and location of open space and recreation areas can be computed. • General nature of solid waste associated with waste sources can be determined. For example, paper, metals and organic materials associated with household wastes. • Gross regional population estimates can be made. (Requires collateral data giving, for example, average occupance per single- or multiple-family dwelling, or average number of employees per industry.) • Quantities of waste within waste source areas and for a region can be estimated (with waste multipliers).
	Panchromatic or Natural Color Stereo Photographs 1:24,000 Scale	Low-Altitude Aircraft	• Within industrial areas an inventory of building type and type of industrial activity can be made. • Computations of floor space and estimated number of employees can be made. • Waste quantities can be computed using detailed industrial waste multipliers, i.e. average quantity of waste generated per industrial employee based on spot-sampling.
	Historical Panchromatic or Color IR Photography 1:24,000 to 1:120,000 Scale	Low to High Altitude Aircraft	• Changes over time within waste source areas can be studied and a region's future waste generating trends may be predicted. • Direction of urban expansion can be determined and potential waste disposal areas in danger of urban encroachment identified.

* Although this paper is oriented toward applications of Remote Sensing to determining waste distributions, characteristics and quantities, this table summarizes on-going Remote-Sensing/Solid-Waste research by the Authors. It is preliminary and subject to modification.

Table 9. *Continued*

Solid-Waste Applications	*Remote-Sensing Record*	*Remote-Sensor Platform Used*	*Remote Sensor Applications (Preliminary)*
Waste Disposal Site Selection and Utilization (Includes: Sanitary Landfill; Incinerators; Recycling and Separation Facilities) †	Color Infrared Photography 1:63,000 to 1:120,000 (Note: Color IR is Preferred Over Natural Color Photography at High Altitude Due to High Tonal Contrasts Between Vegetation/Bare Ground and Cultural Features)	High Altitude Aircraft	• Regional Geology (Especially important when siting sanitary landfills). • Regional Hydrology (particularly surface drainage). • Regional Land Use–the availability of open lands suitable for siting waste disposal sites and the relationship of these areas to surrounding cultural features e.g. local communities or recreational areas can be determined. • Haul Distances–distances from major (urban) waste source areas to waste disposal areas may be computed. • Transportation Routes–major transportation routes from waste source areas to proposed waste disposal area can be identified. • Spatial Distribution of Waste Source Areas. For example, if residential wastes are concentrated in the northern section of an urban area, this may affect the siting of a separation facility geared solely to residential wastes. Economic factors such as transportation costs must be considered. • Waste Quantities–this will determine the number, size or type of waste disposal sites needed for a given region. • Waste Characteristics–may determine the type of waste disposal site(s) needed for the region. • Location of existing excavations (quarries, strip mines etc.) which could be used as waste disposal sites.
Waste Disposal Site Selection and Utilization	Natural Color Color Infrared 1:12,000 Scale (Stereoscopic Coverage)	Low Altitude Aircraft	• Local (proposed site) Geology and Geomorphology. • Local Hydrology–drainage, ponding, potential flood areas. • Potential effects of site location on local communities. • Analysis of vegetation at potential site (may be indicative of soil or drainage variations). • Access to proposed site–the availability and quality of access roads can be determined. • Capacity of existing excavations–life of the site can be estimated.

† Other parameters which are not amenable to study using remote sensing must be investigated when selecting waste disposal sites. Zoning regulations and social attitudes, for example, must be considered.

TABLE 9. *Continued*

Solid-Waste Applications	*Remote-Sensing Record*	*Remote-Sensor Platform Used*	*Remote Sensor Applications (Preliminary)*
Waste Collection and Transportation	Color Infrared, Natural Color, Panchromatic 1:63,000 to 1:120,000	High Altitude Aircraft	• Major road networks can be mapped. (These may lead from major waste source areas to existing or proposed waste disposal areas, or from separation facilities to recycling centers.) • Spatial relationship between rail lines and recycled materials shipping points can be determined. • Waterways for movement of disposable wastes or recycled materials can be mapped. • Street patterns within industrial, residential and commercial waste source areas can be identified and mapped. Once disposal sites are known order of collection within waste source areas can be determined along these identified collection routes. • Estimation of time needed to complete collection and transportation to disposal site (assuming availability of statistics on rates of vehicle movement).
	Panchromatic 1:2400 to 1:10,000 scale	Low Altitude Aircraft	• Traffic surveys to determine optimum time of day for collection and transportation of solid wastes.
Environmental Impact of On-Site and Off-Site Disposal (Site Suitability)	Natural Color Color Infrared Photography 1:12,000 Scale	Low Altitude Aircraft	• Changing water quality adjacent to and within waste disposal sites. • Vegetation destruction within and adjacent to site. • Sheet, rill and gully erosion. • Stream sedimentation from surface runoff. • Stockpiling of hazardous or polluting materials in environmentally "unsafe" areas. • Effects of site operation on wildlife habitats. • Formation of precarious embankments or scarps. • Aesthetic pollution (landscape scarring, abandoned equipment etc.). • Destruction of valuable wildlife resources during site expansion.
	Thermal Imagery ΔT 1°C	Low Altitude Aircraft (Helicopter)	• Underground fires associated with landfills can be detected. • Lechate-polluted outfalls in streams can be detected.

Preliminary testing suggests that small-scale aerial remote-sensing records, and in particular, aerial photographs can play an important role in regional solid-waste management and planning. A principal contribution of remote sensing is determining the spatial distribution of waste producers (categories of waste generating sources). Computation of regional waste quantities from remote-sensing records can fill existing data gaps. Estimates of solid-waste quantities within waste categories can be made given suitable solid-waste multipliers. Multipliers having sufficient detail for high-altitude surveys can be developed nationally through selective spot sampling (field) surveys. Once developed, waste multipliers used in conjunction with data derived from remote sensing can be used to monitor changes in solid-waste quantities at the regional level.

Existing methods for estimating urban waste quantities based mainly upon population statistics apparently vary no more widely than regional statistics acquired using more rapid (and probably less costly) aerial remote-sensing techniques. Satisfactory results can be obtained despite occasional difficulties, e.g., computing recreational or demolition waste quantities. Although primary emphasis has been given to testing methods for determining waste distributions, characteristics and quantities in Tampa, Florida, initial research by the authors suggests that other applications of remote-sensing technology to solid-waste problems appear feasible. These studies will be reported in detail at a later date. A variety of interrelated parameters related to solid-waste site selection and site suitability judgements must be analyzed in planning and managing a regional solid-waste program. Remote sensing can be used to gather a large quantity of the necessary data in a rapid manner and, at the same time, demonstrate important spatial relationships in a single viable format.

References

1. *Preliminary Data Analysis;* 1968 National Survey of Community Solid Waste Practices: U.S. Department of Health, Education, and Welfare; Muhich, Klee, Britton. (483 pp.)
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5. *Solid Waste Management in Recreational Forest Areas;* SW-16ts; by Charles S. Spooner; U.S. Environmental Protection Agency, Solid Waste Management Office, 1971. (96 pp.)

Notice to Contributors

1. Manuscripts should be typed, double-spaced on 8½ × 11 or 8 × 10½ white bond, on *one* side only. References, footnotes, captions—everything should be double-spaced. Margins should be 1½ inches.
2. Ordinarily *two* copies of the manuscript and two sets of illustrations should be submitted where the second set of illustrations need not be prime quality; EXCEPT that *five* copies of papers on Remote Sensing and Photointerpretation are needed, all with prime quality illustrations to facilitate the review process.
3. Each article should include an abstract, which is a *digest* of the article. An abstract should be 100 to 150 words in length.
4. Tables should be designed to fit into a width no more than five inches.
5. Illustrations should not be more than twice the final print size: *glossy* prints of photos should be submitted. Lettering should be neat, and designed for the reduction anticipated. Please include a separate list of captions.
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