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Socioeconomic Environmental Studies Series

Land Use Forms and the Environment - An Executive Summary

Office of Research and Development
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Land Use Forms

and the Environment

An Executive Summary

by

Brian J. L. Berry

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Project Officer

Dr. Philip D. Patterson
Washington Environmental Research Center
Washington, D.C. 20460

Prepared for
OFFICE OF RESEARCH AND DEVELOPMENT
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WASHINGTON, D.C. 20460

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This executive summary of the final report of Grant 8D1419, which was sponsored by The Washington Environment Research Center, Office of Research and Development, U. S. Environmental Protection Agency, was completed by members of the Department of Geography and Center for Urban Studies, University of Chicago. The project director was Brian J. L. Berry and the EPA project officer was Philip D. Patterson.

I. CONCLUSIONS

The relationships between the size and economic functions of metropolitan regions, the income levels of their residents, and the nature and intensity of environmental pollution have been documented and clarified in a number of recent studies. The most important finding of the study summarized here is that -- in 1970, metropolitan regions of similar sizes, economic functions and income levels had different urban forms; that as urban form varied, so did the urban land use pattern; and that as land use varied, so did environmental pollution. In particular, it was concluded that high-density, concentrated, core-oriented urban regions had superior air and water quality to sprawling, dispersed urban regions of similar size and economic functions.

This conclusion is important, because urban form is itself determined by the modal mix of transportation and the location of transport routes, employment complexes, airports and open spaces, and each of these is to some extent controllable by land use planning. Thus, to the extent that variations in urban form produce variations in environmental pollution, land use planning becomes a positive instrument for achieving environmental quality goals.

A second conclusion points to the difficulties of this task, however. Many economists agree that property values measure the net benefits expected to flow over the useful life of an investment in a particular land use, taking into account both the economies derived from urban agglomerations and the environmental and social costs of urban life. Following this logic, the aggregate property values of metropolitan regions, should therefore reflect the total stream of benefits expected to flow from the land uses within each region. The research summarized here concluded that aggregate property values, as expected, increase with city size and with income levels and decrease with the size of manufacturing concentrations. But most importantly, the aggregate property values are greater in more dispersed regions than they are in metropolitan areas with more concentrated urban forms. As measured by 1967 property values and 1970 air pollution levels, there is therefore a conflict between the economically most desirable urban form (sprawl), and the environmentally most desirable form (concentration). The urban regions that are emerging reflect market responses to the greater aggregate net benefits in the more dispersed urban forms. Decentralization in our cities appears to be continuing apace, with the apparent consequence of increasing metropolitan environmental quality problems. Herein is the challenge to those who would formulate a national land use policy.

II. BACKGROUND

A few words of background are important. Under the provisions of Project No. R-801419, "Land Use Forms and the Environment", undertaken for the Washington Environmental Research Center, Office of Research and Development, U.S. Environmental Protection Agency by a research group at the University of Chicago, a voluminous final report was submitted to EPA in November, 1973. This report was published in April, 1974 under the title Land Use, Urban Form and Environmental Quality (The University of Chicago: Department of Geography Research Paper No. 155, 1974, xxiv and 438 pages). It was felt by the Agency's staff that the report was too long and too technical for wide circulation, and so an "executive summary" was requested to highlight the principal conclusions. This is that summary.

It is important to realize what is summarized and what has been excluded from the pages that follow. When our research began in the summer of 1972 we searched in vain for sources--both within and outside EPA--to which we could turn for reasonably concise guides to the nature and sources of each type of environmental pollution, to the measurement systems and surveillance networks now in use, to the data currently available, to the latest information on effluent and emission sources and amounts, to the incidence of pollution, to assessments of quality in terms of national and/or local standards, and to what is known about health and welfare effects of pollution, the presumed bases of the standards. As might have been expected, the search was difficult. No agency has the responsibility for drawing together all that is known, although EPA is now doing more than most.

Therefore, for each aspect of environmental quality we were expected to address in our research--air, water, solid wastes, noise, pesticides and radiation--we culled the literature, badgered the relevant organizations and agencies, and pulled together our own summary and assessment of current pollutant data sources and environmental quality assessment systems. Six chapters of the larger report, one for each pollutant, are devoted to these summaries. The 250 pages involved provide an identically-structured treatment of each pollutant, looking in turn at measurement systems, generation information, quality assessment, and health and welfare effects. The person who needs the kind of reference system and background knowledge that we found to be lacking when we began our research should turn to the larger report, because these background materials are <u>not</u> reviewed in this summary.

Instead, this document focuses on the original findings of the research group, comprising faculty members and students in the Department of Geography and/or the Center for Urban Studies of the University of Chicago. The findings relate urban form and environmental pollution (a) across the spectrum of U.S. metropolitan areas considered as entities, and (b) on a more detailed basis within a sample of these urban regions, at a point in time centering on the 1970 census year. In both cases, the research involved painstaking data collection and many experimental statistical analyses. Again, the details of this research will not be addressed in this summary; the full report is the place for these. Rather, we will highlight the results that appear to hold most significance for public policies that affect the relationship between land use, urban form and environmental quality.

Because this is a summary, many of the obvious caveats about data quality, gaps in knowledge, and the like will remain unsaid. Yet, lest there be any doubts about the matter, the research group's findings concerning environmental data should be known at the outset:

> Collection of data on environmental quality is in a developmental state at this time. Gaps and inconsistencies abound. The nation's environmental data banks either use the available monitoring networks selectively and incompletely or assemble all available data, regardless of source, completeness or quality into an often poorly-functioning data bank. In other cases (e.g., solid wastes and noise) comparative nationwide information is totally lacking, or is at a scale that does not permit detailed investigation of the effects of different urban forms on environmental quality (e.g., pesticides and radiation).

Much effort on the environmental information side will have to be expended before research of the kind we report here can progress beyond the exploratory and experimental stage. That such effort might be well-spent is, however, indicated by our results: we do find, subject to all the qualifications above, that different urban forms had significant effects on environmental quality in 1970.

III. CONCEPTS

The finding that urban form affects environmental quality is to be understood within the framework of a conceptual scheme that was used to structure the research and a body of data that was used to test the validity of the concepts.

In the first part of the study, in which entire metropolitan areas were used as units of analysis, the conceptual scheme was derived from contemporary urban economic theory. For purposes of the study, such city characteristics as population size, the nature of the urban economic base and the income levels of the area's residents were taken as "givens," determined by the role played by the city within the national economy. The question was one of exactly how urban activities are translated into land use and how land use relates to environmental pollution.

Urban form, as indicated by population density patterns, the nature of the highway network, etc., was hypothesized to play an important role in the translation of city characteristics into land use. The transport network, for example, helps determine the location of economic activities and residences, and whether the urban region has a radial structure from a dominant central business district, or whether it is sprawling and multi-centered. Whether or not the urban structure is highly concentrated or dispersed determines the land supply and, at any given level of demand for land, whether the land is used intensively or extensively. Concentration and dispersion, in turn, both result from and help determine the transportation patterns of the metropolitan region and along with the size and affluence of a community are reflected in the pattern of urban densities.

In turn, land use was hypothesized to determine land values. Given well-functioning markets, it is a well-established principle of urban economics that the price of land and the capital assets located on it will equal the present value of the future stream of net benefits expected to flow over the useful life of the assets -- increased, as several economists have recently pointed out, by the positive externalities derived from others, as well as being reduced by such negative externalities as pollution* imposed by others. If this is true for each individual property within a metropolitan area, it should also be true of the sum total for all properties within that region: aggregate land values should include the agglomeration economies of large urban complexes, and should be reduced by such disbenefits as the costs imposed by discharge of pollutants into the urban environment. Further, high property values should contribute to the comparative advantage of the urban region in the national economy, attracting investment, while low values resulting from higher levels of environmental pollution and/or from other effects should detract from this comparative advantage.

* To the extent that buyers and sellers of property are aware of the actual damages caused by pollution and other externalities.

The overall conceptual model is depicted in Figure 1. In keeping with what has just been said, it postulates that urban characteristics are the determinants of land use, with an intervening role played by urban form (causal influences are indicated by arrows). Land use is seen as determining land values, but the land use pattern is, in turn, also seen to be the source of the environmental pollution that reduces these values.

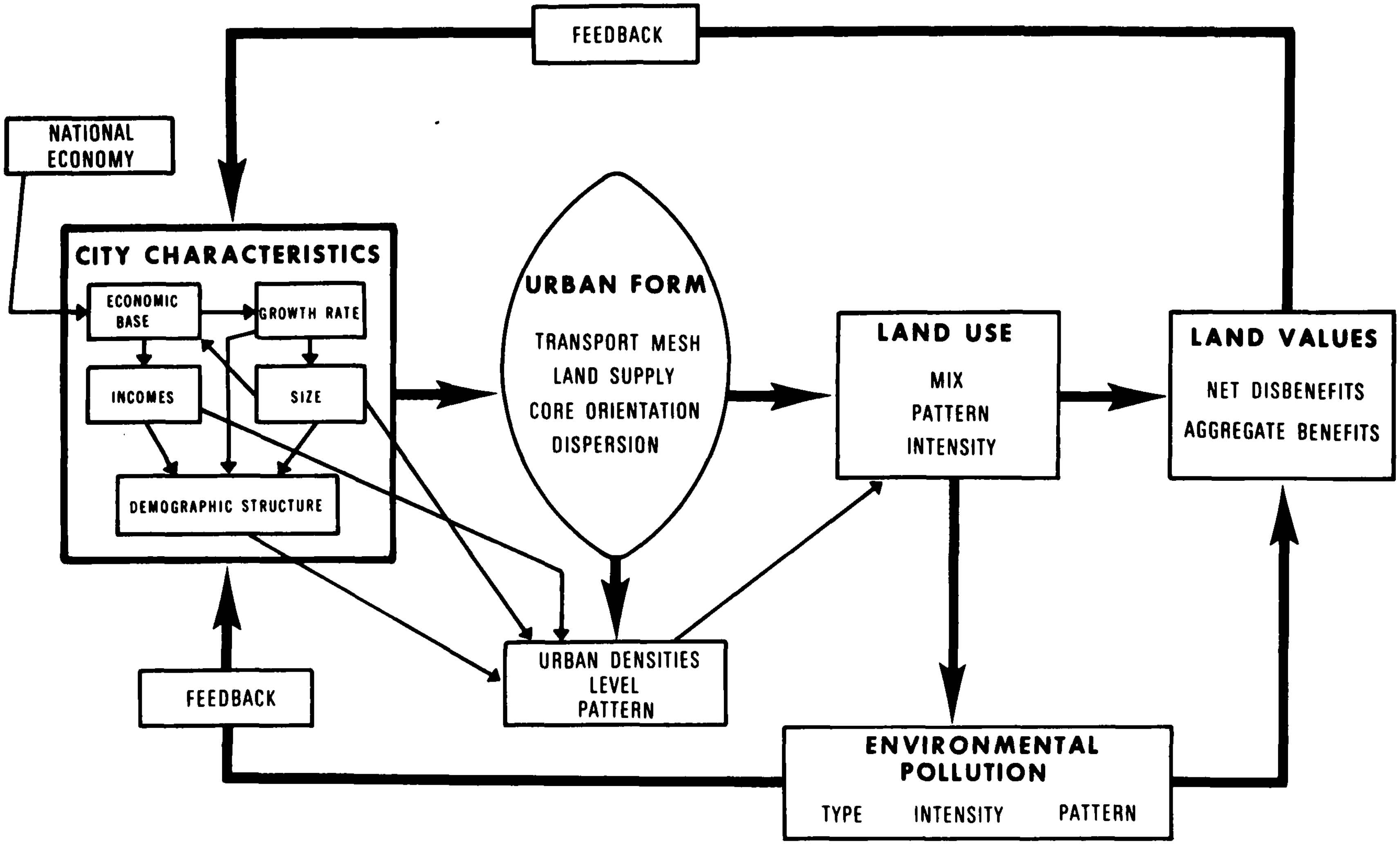
Consistent with this conceptual model, the research strategy at the metropolitan scale was to study the following:

> (i) Environmental pollution as a function of land use, land use as a function of urban form and city characteristics, and environmental pollution as a function of urban form and city characteristics, to determine the ways in which urban form translates city characteristics into land use, and its role therefore in enhancing or reducing the environmental pollution that results from urban size, economic base, and income levels.
>
> (ii) Land values as a function of city characteristics, urban form and environmental pollution, to measure the ways in which agglomeration economies and negative externalities intertwine.

At the intra-metropolitan scale, because of serious data limitations, the research was more experimental, designed to open up lines of research inquiry. Details of the urban land use pattern were related to details of the pollution map on a case-study basis following the logic outlined in Figure 2, in which the circular relationships between the urban land use pattern and the pollution map are spelled

Figure 1

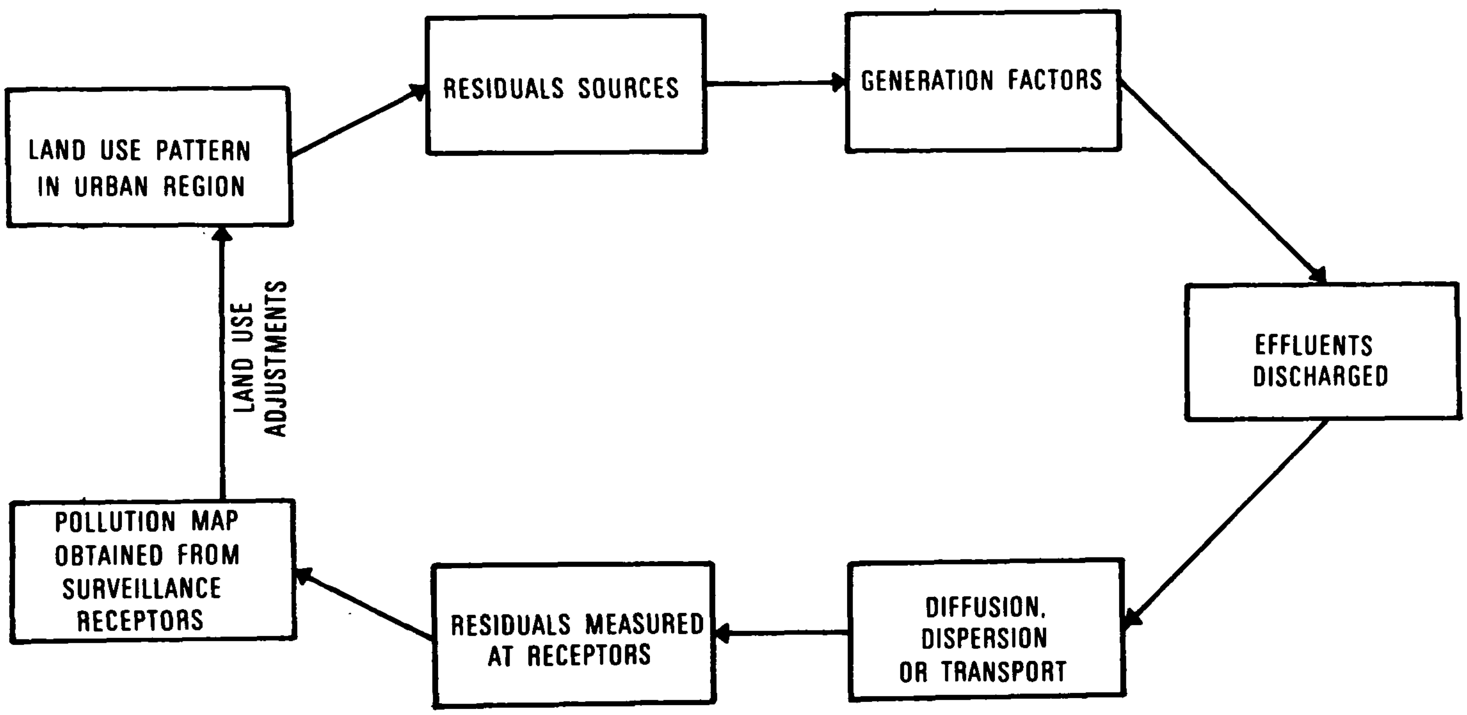
OVERALL CONCEPTUAL MODEL



out. Only in the case of air pollution were comparisons of several metropolitan areas possible on a detailed intra-metropolitan basis.

FIGURE 2

CONCEPTUAL MODEL USED IN THE FORMULATION
INTRA-METROPOLITAN STUDIES

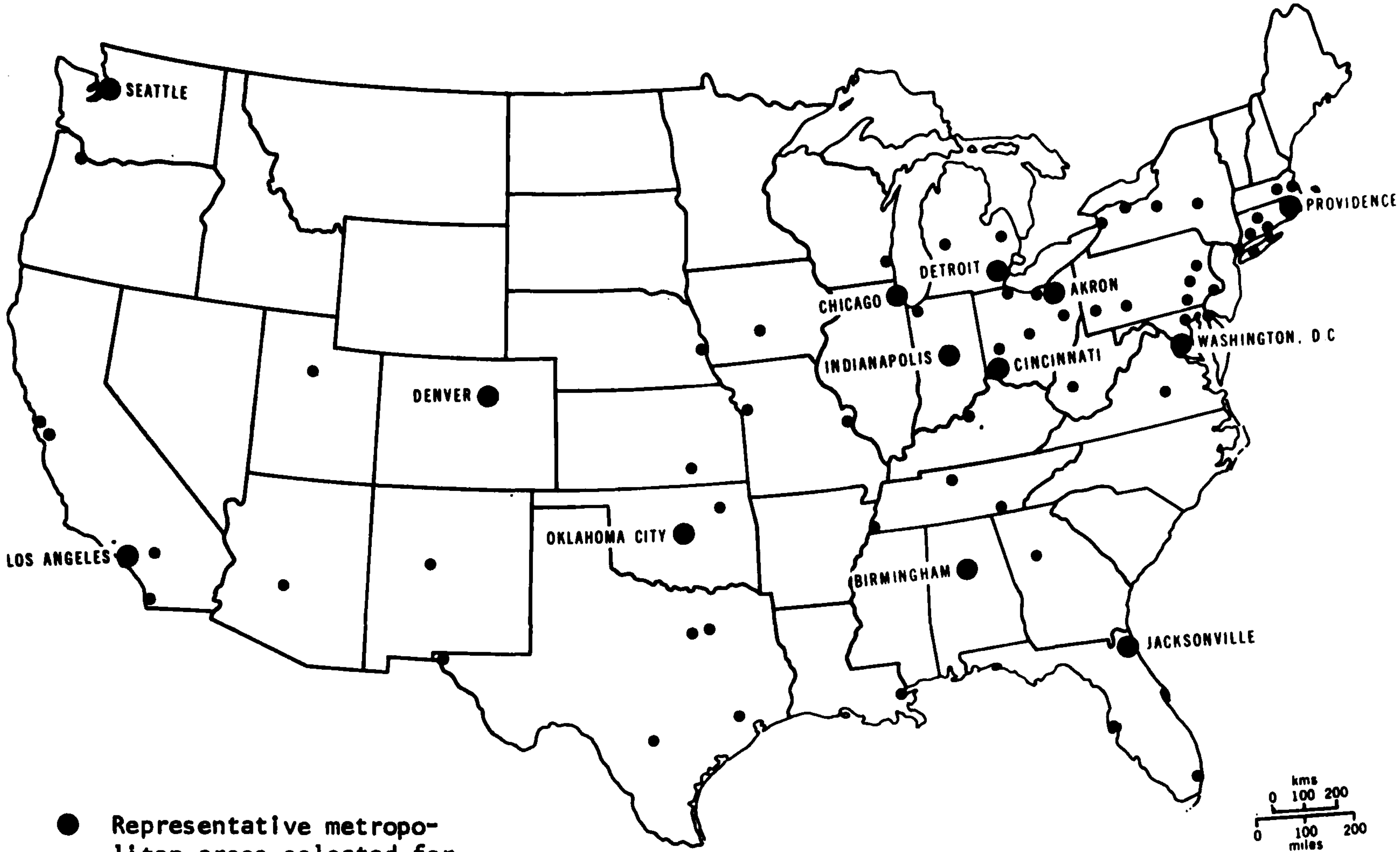


IV. THE GROUPING OF METROPOLITAN AREAS

A. The Sorting Table

In all, 76 metropolitan regions were studied. The Standard Metropolitan Statistical Area (SMSA), as defined by the Office of Management and Budget, was used as the unit of analysis. These regions, whose locations are shown in Figure 3, are as follows:

Akron	Milwaukee
Albuquerque	Minneapolis-St. Paul
Allentown-Bethelem-Easton	Nashville-Davidson
Atlanta	New Haven
Baltimore	New Orleans
Birmingham	New York
Boston	Newark
Bridgeport	Norfolk-Portsmouth
Buffalo	Oklahoma City
Canton	Omaha
Charleston, W. Va.	Paterson-Clifton-Passaic
Chattanooga	Philadelphia
Chicago	Phoenix
Cincinnati	Pittsburgh
Cleveland	Portland, O.
Columbus, Ohio	Providence-Pawtucket-Warwick
Dallas	Reading
Dayton	Richmond
Denver	Rochester, N.Y.
Des Moines	St. Louis
Detroit	Salt Lake City
El Paso	San Antonio
Flint	San Bernadino-Riverside-Ontario
Fort Worth	San Diego
Gary-Hammond-East Chicago	San Francisco-Oakland
Grand Rapids	San Jose
Hartford	Seattle-Everett
Honolulu	Syracuse
Houston	Tampa-St. Petersburg
Indianapolis	Toledo
Jacksonville	Tulsa
Jersey City	Utica-Rome
Johnstown	Washington, D.C.
Kansas City	Wichita
Los Angeles-Long Beach	Wilmington
Louisville	Worcester
Memphis	York
Miami	Youngstown-Warren



● Representative metropolitan areas selected for use in intra-metropolitan analysis

FIGURE 3

METROPOLITAN AREAS USED IN THE INTER-METROPOLITAN ANALYSIS

The first task completed in the project was to group these SMSA's into subsets on the basis of their pollution characteristics, so that the environmental dissimilarity among the subsets was maximized and the environmental dissimilarity among the SMSA's within each subset was minimized. The subsets then were used to prepare a "sorting table" that showed how each SMSA fitted into the nationwide spectrum of variations in urban environmental pollution.

Table 1 summarizes this sorting table and Table 2 shows how the groups of SMSA's differ in terms of several key urban indicators. Some clear contrasts are evident between those groups of cities with high levels of air pollution, for example, and those with poor water quality.

The classification of the SMSA's into relatively homogeneous subsets on the basis of their pollution characteristics was undertaken for several reasons. One, as noted, was to learn more about nationwide variations in urban environmental quality. Another was to facilitate acquisition of more detailed local data on a sampling basis, with some guarantee that the sample of SMSA's selected would span the universe of pollution types. The SMSA's underlined in Tables 1 and 2 and shown by large dots in Figure 1, are those which were selected as representative of these groups. It was for these SMSA's that detailed metropolitan land use data were derived to be used in the later analysis.

TABLE 1

THE ENVIRONMENTAL SORTING TABLE

GROUP OF CITIES

ENVIRONMENTAL QUALITY INDICATORS:	Baltimore Buffalo Indianapolis Los Angeles Washington D.C.	Chicago Milwaukee Minneapolis Philadelphia Pittsburgh Portland St. Louis	Akron Allentown-Bethlehem Canton Rochester Youngstown York	Birmingham Charleston Chattanooga Dayton Des Moines Gary-Hammond Johnstown Nashville Omaha Reading Utica-Rome Worcester	Bridgeport Cleveland Hartford New Haven Newark Providence	Flint Grand Rapids Jacksonville Louisville Norfolk Patterson Richmond Toledo	Cincinnati Jersey City Kansas City San Bernadino Syracuse Wilmington	Atlanta Boston Columbus Dallas Detroit Fort Worth Houston Miami New Orleans New York San Antonio San Diego San Francisco San Jose Seattle Tampa-St. Petersburg	Honolulu Memphis	Albuquerque El Paso Oklahoma City Phoenix Tulsa Wichita	Denver Salt Lake City
1. Water											
Dissolved oxygen	7.2	8.0	5.3	7.8	7.1	7.9	7.0	6.9	-	4.9	-
Dissolved solids	865	211	820	353	95	407	4765	4448	-	1,894	445
Nitrates	3	5	16	3	4	3	8	19	-	16	11
Average WQ Index	5.1	1.2	2.8	1.6	2.1	2.2	4.5	3.3	-	2.3	1.3
2. Air											
Average SO_2	34	49	38	25	51	20	22	19	16	9	13
Average TSP	115	117	106	119	84	82	104	85	61	84	82
Average AQ Index	3.2	3.4	2.7	3.2	2.7	2.1	2.9	2.3	2.3	2.1	2.2
Average EV Index	9.7	8.4	5.9	10.6	4.2	2.2	5.0	3.5	2.3	3.4	1.1
3. Solid Wastes											
Generated by individual multipliers	5,897	6,737	1,440	999	2,482	1,434	1,940	4,527	1,174	984	1,564
4. Noise											
Air travel Index	170	228	194	36	99	34	66	152	114	46	110

TABLE 2

KEY URBAN INDICATORS

GROUP OF CITIES

URBAN CHARACTERISTICS:	Baltimore Buffalo Indianapolis Los Angeles Washington D.C.	Chicago Milwaukee Minneapolis Philadelphia Pittsburgh Portland St. Louis	Akron Allentown- Bethlehem Canton Rochester Youngstown York	Birmingham Charleston Chattanooga Dayton Des Moines Gary- Hammond Johnstown Nashville Omaha Reading Utica-Rome Worcester	Bridgeport Cleveland Hartford New Haven Newark Providence	Flint Grand Rapids Jacksonville Louisville Norfolk Patterson Richmond Toledo	Cincinnati Jersey City Kansas City San Bernadino Syracuse Wilmington	Atlanta Boston Columbus Dallas Detroit Fort Worth Houston Miami New Orleans New York San Antonio San Diego San Francisco San Jose Seattle Tampa-St. Petersburg	Honolulu Memphis	Albuquerque El Paso Oklahoma City Phoenix Tulsa Wichita	Denver Salt Lake City
Population (in thousands)	2,285	2,969	557	448	1,040	705	921	2,267	700	525	893
Percent employed in manufacturing	24.2	29.8	43.9	32.5	34.0	29.4	30.3	22.0	14.7	19.9	16.4
Median family income (in thousands)	11.1	10.9	10.6	9.7	11.4	10.3	10.2	10.4	10.3	9.1	10.4
Urban property values (billions)	25.2	18.5	3.4	3.1	10.3	4.7	8.5	18.8	4.1	3.4	6.6
URBAN FORM INDICATORS:											
Central density (sample city)	17,000	36,022	10,931	7,216	11,867	-	10,558	15,500	-	4,322	10,198
Density gradient (sample city)	-.168	-.1281	-.3244	-.2345	-.2687	-	-.1543	-.107	-	-.1714	-.1498
Radial highways	10.6	10.9	5.0	5.4	7.5	6.6	7.5	8.3	5.5	4.0	7.0
Circumferential highways	3.0	2.7	2.5	1.5	1.6	1.7	1.8	2.4	2.0	3.0	1.5
Open Space Percent	71.1	70.7	78.5	67.3	81.6	82.1	84.1	73.0	-	84.6	83.8

B. Pollution Data Used in the Grouping

The environmental variables used to derive the groups of cities shown in the sorting table were as follows:

AIR POLLUTANTS (data for 73 SMSA's)

Sulfur Dioxide (SO_2)	(a) Annual Mean Concentration ($\mu g/m^3$)
	(b) Annual Maximum Concentration ($\mu g/m^3$)
Total Suspended Particulates (TSP)	(a) Annual Mean Concentration ($\mu g/m^3$)
	(b) Annual Maximum Concentration ($\mu g/m^3$)

DERIVED AIR QUALITY INDEXES (Source: The Mitre Corporation)

Mitre Air Quality Index (data for 67 SMSA's)

(a) SO_2	index numbers
(b) TSP	index numbers
(c) NO_2	index numbers
(d) All Pollutants	index numbers

Extreme Value Index (data for 59 SMSA's)

(a) SO_2	index numbers
(b) TSP	index numbers
(c) All Pollutants	index numbers

WATER QUALITY PARAMETERS (data for 44 SMSA's)

Temperature	Degrees Fahrenheit
Color	Platinum-Cobalt Units
Turbidity	Jackson Turbidity Units
p^H	p^H values
Fecal Coliform Bacteria	MPN/100 ml.
Total Dissolved Solid	ppm (residue at 180° C.)
Suspended Solids	Parts per million
Total Nitrogen	Parts per million
Alkalinity	Parts per million (as CaC)
Hardness	Parts per million (Ca, Mg)
Chlorides	Parts per million
Total Iron and Manganese	Parts per million
Sulfate	Parts per million
Dissolved Oxygen	Parts per million

DERIVED WATER QUALITY INDEXES (data for 44 SMSA's)

Water Quality Index, Drinking Use	index numbers
Water Quality Index, Recreation Use	index numbers
Water Quality Index, Industrial Use	index numbers
Mean Water Quality Index (averages of above 3)	index numbers

SOLID WASTE ESTIMATES (data for 76 SMSA's)

Total Calculated from Simple Generation Rate	1,000's tons/year
Total Calculated from Separate Source Unit Estimators	1,000's tons/year
Same as second above, omitting manufacturing	1,000's tons/year

NOISE--SURROGATE INDICATORS (data for 76 SMSA's)

Automobile Traffic Volume	Number of workers using private automobiles to commuted to work, SMSA
Air Traffic Volume	Number of scheduled aircraft arrivals and departures, SMSA

C. Factor Analysis of the Pollution Data

As noted, the above data were subjected to a factor analysis, the purpose of which was to group the 76 SMSA's into subsets in such a manner that the dissimilarity among the subsets is maximized and the dissimilarity among SMSA's within the subsets is minimized.

Factor analysis is a complex mathematical procedure that cannot be undertaken without a large computer. In the application here it was used to explore the similarities and differences among the SMSA's, simultaneously considering the 34 pollution variables listed above. The result of the analysis was to determine that the 76 SMSA's should be classified into the eleven groups shown in the sorting table.

D. The Urban Characteristics

In addition to the pollution data, a set of city characteristics also was assembled to be used in the subsequent investigation, viz:

CITY CHARACTERISTICS (76 SMSA's)

1970	Central City Population	1000's
	SMSA Population	1000's
	Central City Density	Pop./square mile
	SMSA Density	Pop./square mile
1960-70	Population Change, CITY	percent
	Population Change, SMSA	percent
1970	Median Age of Population, City	years of age
	Median Age of Population, SMSA	years of age
	Median Family Income	$
	Percent of Labor Force Employed in Manufacturing	percent
	Land Area, City	square miles
1967	Total Value of Real Estate, SMSA	$1,000,000's

URBAN FORM INDICATORS (76 SMSA's)

Degrees of Arc of SMSA around CBD	0° to 360°
Density Ratio	(SMSA density/city density)
Transportation Radials, SMSA	number
Transportation Circumferentials, SMSA	number

Finally, after the factor analysis had provided a pollution-sensitive classification of the SMSA's, a sample of 13 cases was selected, with one from each of the groups, both to enable preparation of metropolitan land-use estimates and to limit the scope of the subsequent intra-metropolitan analysis. The land use variables collected were as follows:

SMSA LAND USE (13 representative SMSA's)

Residential	Percentage of total area
Commercial	Percentage of total area
Industrial	Percentage of total area
Extractive	Percentage of total area
Public and Semipublic	Percentage of total area
Transportation, Communications, Utilities (TCU)	Percentage of total area
Open Space	Percentage of total area

V. INTER-METROPOLITAN ANALYSIS

A. Findings Related to Property Values

One stage in the analysis involved an examination of the relationships between the total value of property in each of the 76 metropolitan areas, the size and other characteristics of the SMSA's, the agglomeration economies accompanying concentration of activity in these urban areas, and the negative externalities of growth, including environmental pollution.

It is pointed out in the existing literature of urban economics that the net benefits of urban life should, first of all, vary directly with the size of the metropolis. The larger the city, the greater the size of market that can be reached, the greater the access to information about new products and processes, the better the access to a wide range of specialized suppliers, and the easier it is to recruit and retain a specialized workforce. In industries marked by uncertain and fluctuating demands, there are advantages in being located in a city where specialized inputs can be obtained quickly. For households, there are advantages of a larger range of potential employment opportunities, varied and specialized sources of consumer goods and services, and access to those cultural activities that are available only in the larger cities. Such benefits should become manifest through improved productivity, and a resulting stream of net benefits that therefore increases directly with city size.

Another well-established principle in economics is that, given well-functioning markets, the price of any capital asset will equal the present value of the anticipated future stream of net benefits over the useful life of the asset. Thus, summing over the properties within any metropolitan area, aggregate property values should provide a first approximation of the stream of net benefits expected to accrue to land users within that area, and a means of estimating the effects of economics of agglomeration on those benefits. In other words, the market for land and property within urban areas should capture and express the net benefits of urban growth and size.

If this is so, then one question that arises is whether, if urban form affects land use, the stream of net benefits varies with differences in urban form. Urban planners frequently argue, for example, that disorderly urban sprawl destroys property values. A second question is whether these benefits are reduced by environmental pollution. Both economies and diseconomies of agglomeration will come into play with increasing metropolitan size. New activities provide additional opportunities for specialization or integration of activities or improved quality of information. These can be either pecuniary or physical external economies in production or consumption. If there are scale economies in provision of public services, additional population gives rise to decreasing average costs of services, which will result in a higher quality of services per tax dollar.

At the same time, diseconomies of agglomeration will result from congestion and pollution, or from decreasing returns to scale in the public service sector.

A series of empirically-testable propositions arise from the foregoing:

(1) Aggregate property values and total population should move systematically together, in the absence of net economies or diseconomies of agglomeration, in a linear fashion.

(2) If there are net economies of agglomeration over some size range, property values should increase more than proportionally with population.

(3) With net diseconomies, property values should increase less than proportionally with population, and if diseconomies become sufficiently severe, property values should actually decline as population increases.

(4) If there are increasing returns to city size, followed by decreasing returns, aggregate property values should increase in an S-shaped logistic pattern with respect to population, and it should then be possible to identify that point at which average land value per person is maximized, the population size which is optimal in an economic sense for all cities in the system in the long run, as well as that point (the lower inflection point) at which the marginal increment in land value from an incremental change in population is maximized. This latter point is that size at which the marginal contribution of population to land values is largest in the short run.

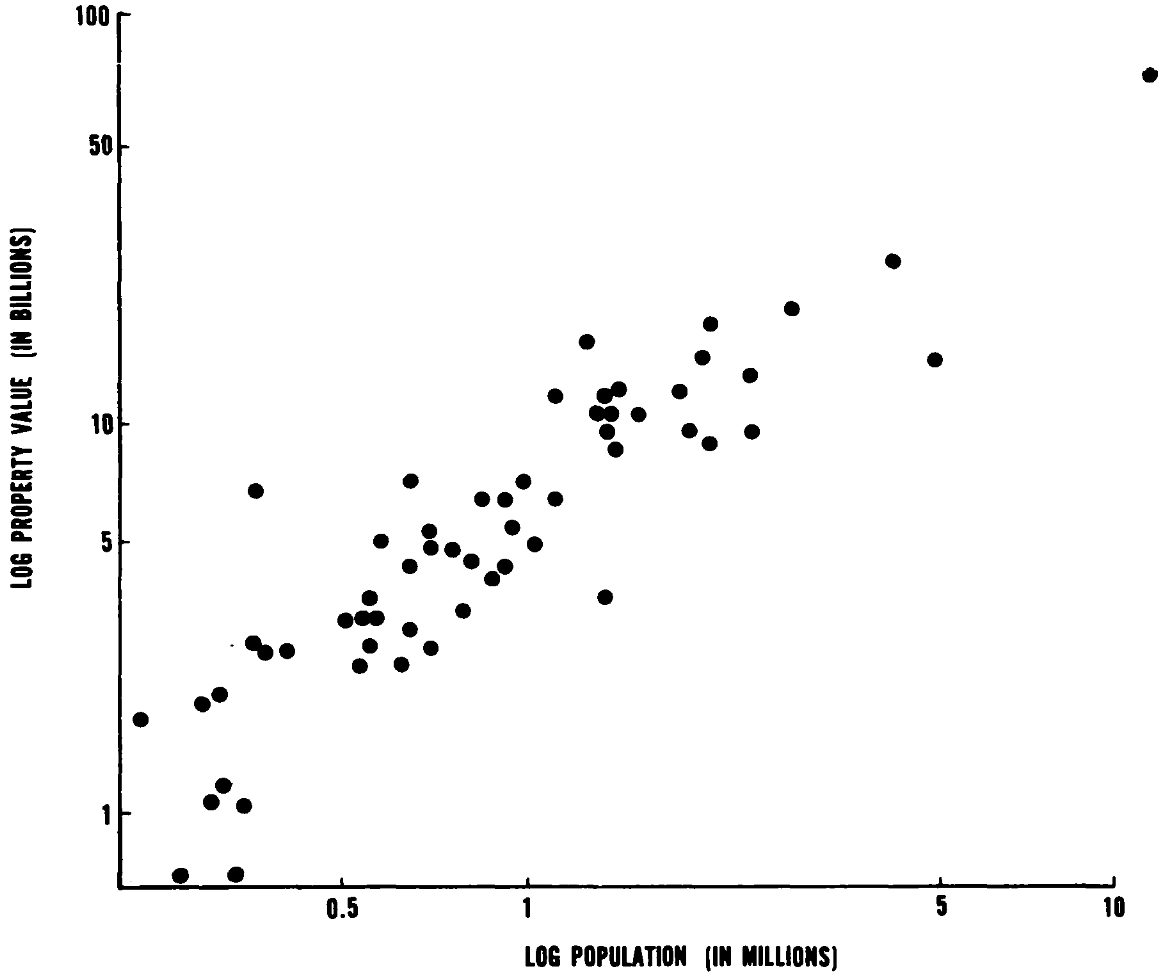
(5) To the extent that manufacturing concentrations increase environmental pollution and environmental quality is better in higher-income communities, these variables should account for a significant portion of the variance from (1).

(6) If the dispersed city, holding constant city characteristics, produces a land use mix delivering lower environmental quality, this should be reflected in appropriate statistically-significant partial relationships of urban form and aggregate land values.

In testing these propositions, the dependent variable, total property values, was derived from assessment data in the 1967 Census of Governments, with adjustments made to the market value using the assessment ratios in that publication. The independent variables that were used are those listed in the previous section. Figure 4 plots the observed property values against metropolitan population. Our interest centered, first, on the shape of this relationship, and then on the sources of variability including the possible contributions of urban form and environmental pollution to the variance.

FIGURE 4

AGGREGATE PROPERTY VALUES RELATED
TO SMSA POPULATION



Source of Data: 1967 Census of Government and
1970 Census of Population

After completing many multiple regression analyses the following findings emerged: aggregate property values and metropolitan size increase in a highly correlated manner (elasticity* in the range 0.85 to 0.89), but are depressed by manufacturing concentrations (elasticity -0.37 to -0.45) and assume much higher levels in higher-income cities (elasticity 2.14 to 2.33). Some economists believe that to the extent that median incomes reflect real-wage differentials, they are the necessary "bribes" that must be paid to attract and retain the urban labor force in congested, polluted, inadequately serviced, dangerous, and impersonal large cities. However, our results belie this supposition; environmental quality was found to be much better in higher-income cities than in lower-income cities.

There were some negative conclusions, too. In particular, none of the variables used to index levels of environmental pollution was statistically significant in any of the regression models. Apparently, once the effects of population size, manufacturing concentrations and income levels had been taken into account, the main sources of variation in overall levels of environmental pollution also had been accounted for!

Separate studies were made of different size-classes of cities, and even within size classes, city size remained an important deter-

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* Elasticity is the percent change in the dependent variable resulting from a 1 percent change in the independent variable. For example, in this case, an elasticity of .85 means that aggregate property values go up .85 percent for every one percent increase in metropolitan population.

minant of property values, and manufacturing concentrations continued to depress them. The most complex analyses explored whether the relationship between property values and city size was straight-line or S-shaped. The latter was found to be the case. Net agglomeration economies were found to be present in urban regions up to a size of 2.5 millions, with maximum property values per capita in urban regions of around 1 million people. However, progressively greater net diseconomies of size were found to take their toll in metropolitan regions between 2.5 millions and 6.0 millions in size. But increasing returns were found thereafter in the largest urban regions. Reiterating earlier conclusions, variables representing levels of environmental pollution added no explanation to this most complex model not already provided by size, economic base and income levels. This means that the effects of pollution, congestion and crime on the quality of urban life show up (a) in the fact that the elasticity of property values with respect to population size is less than one (property values increase less rapidly than population; (b) in the fact that the coefficient attached to manufacturing concentrations is negative (more manufacturing activity depresses property values), and (c) that there is a self-selectivity reflected in the positive large relationship of property values to income levels.

There were, though, some significant relationships of property values to the urban form variables. In particular, aggregate property values were found to be greater in lower-density (dispersed) urban regions than in high-density (concentrated) urban centers. The rapid continuing decentralization of American urban regions is consistent with adjustments to urban form in response to these net benefits of dispersion, thus confirming the thrust of the statistical conclusions.

B. Findings Related to Land Use Relationships

Regression models also were formulated and tested, using the smaller sample set of 13 SMSA's, to determine, firstly, the relationships between land use, city characteristics and urban form, and secondly the relationships between environmental pollution and land use.

In the first case, each land use type was initially regressed on such city characteristics as size, manufacturing concentrations, etc., and then on these variables plus the urban form indicators. In all cases except two, the amount of variation in the land use variable explained by the equation more than doubled when the urban form indicators were included in the equations, indicating that urban form plays a significant role in translating city characteristics into land use. The exceptions are industrial land use and transport-communication-utilities (TCU). In economic models, it is commonly assumed that industrial location is determined by the role played by a city in the national economy, and that TCU represents a key instrument variable that may be used to shape land use, and the results of the analyses certainly seemed to confirm this supposition that industry and transportation are determinants of urban structure rather than being determined by it.

As for the other land uses, the important intervening role of urban form in determining the urban land use mix was clear. For example, the percentage of land used for residential purposes was found to vary in the following ways: directly with SMSA population, with a 1.0 percent change in population producing an 0.6 percent change in the residential percentage; inversely with income levels; and positively with manufacturing employment. The less-than-proportionate rate of increase of residential land use with city size is commensurate with the fact that city area also increases at a slower rate than urban population, producing increased residential densities, and was borne out by an inverse relationship found to exist between the residential percentage and the density ratio: the percentage of residential land increases as the density ratio falls. Because the density ratio falls when central city densities are high relative to SMSA densities (i.e., a situation in which the population density gradient* is relatively steep and the population of the urban area is core-oriented), higher central city densities produce more intensive land use and a relatively lower residential percentage.

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* The density gradient charts the rate of decline of densities with increasing distance from the city center. A steep gradient indicates that densities drop very quickly; a shallow gradient indicates a much more uniform population density pattern.

The greatest elasticity of residential land use was found to be with respect to median incomes; a 1.0 percent increase in incomes was associated with a 2.1 percentage point decrease in residential land use. The compensating factor apparently was open space: another equation showed that the greater the median income of a community, the greater the open space, commensurate with national attitudes regarding the quality of life.

The intervening role of the three urban form variables revealed the specific mechanics by which city characteristics are translated into land use. A positive relationship was found between the residential percentage and the "degrees of arc" covered by a city. The higher the degrees of arc, (i.e., the greater the approximation of the city to a full circle around its center), the more area is available for residential development, and the more extensive is land use. On the other hand, residential land use varies inversely with the number of radial highways. Planners have advocated the use of a radial urban design to cut down on urban sprawl. By concentrating development along the radials or "fingers," and restricting the uses of the "wedges" between these fingers, according to the argument, land development might be confined to the easily accessible areas, occurring at higher density and leaving more open space. The inverse relationship shown here supports this argument, as does the positive relationship between the residential percentage and the number of circumferential highways. An increased number of circumferentials promotes residential sprawl.

What, then, are the mechanics of these urban form relationships that have been suggested? What is indicated is that the <u>demand</u> for urban land is determined by the role that the city plays in the national economy. From such relationships arise the industry mix, growth rate, size, and income levels of the urban region. Urban form controls the <u>supply</u> of land of each access type available for development. The greatest supply of land is delivered by a circular urban region with many circumferential highway rings; such supply conditions produce residential sprawl. On the other hand a radially-structured urban region on a restricted site has higher residential densities, a steeper density gradient, a lower residential land use percentage, and more open space.

Similar relationships exist for the other land uses. The commercial and extractive percentages increase with city size, are lower where the density gradient is steep, decrease with community income levels, and increase in manufacturing cities. They increase as the urban form approaches circularity, decrease in a radial structure and increase with the number of circumferentials.

Conversely, open space decreases with city size, manufacturing concentrations, and circumferential structure, increases with income levels, where the density gradient is steep, and with the number of radials, and -- the only surprise -- decreases as the degrees of arc increase. But a moment's reflection eliminates even that surprise.

Departures from circularity are usually environmentally-determined by lakes and seashore, rivers and mountains, and where such environmental amenities exist, there has been effort to preserve them as open space.

The final step in this phase of the analysis was to relate environmental pollution to land use. Each of the air and water quality variables was regressed directly on the city characteristics and indicators of urban form, with very mixed results. When, however, these same variables were related to the land use variables instead, highly significant results emerged, thus confirming the general logic of the conceptual sequence diagrammed in Figure 1. Apparently, urban forms are expressed in environmental pollution through the intervening role of land use, just as urban form, in turn, translates city characteristics into land use. Basically, size, manufacturing concentrations and low incomes, combined with urban configurations that permit extensive sprawl, produce land use mixes that have associated with them the greatest environmental pollution.

C. Comparison with Intra-Metropolitan Property Value Studies

One question about the foregoing macro-scale conclusions (i.e. findings related to metropolitan regions as a whole) is how they relate to micro-scale conclusions about the effects of environmental pollution on property values. For samples of individual properties within particular cities, many recent investigators have found that property values decline as environmental pollution increases. Why should this fact not be reflected at the macro-scale of the foregoing inquiry? The answer is that the individual effects are present in all cities, varying in the magnitude of their incidence with city size, with the scale of manufacturing concentrations, and with income levels. They are thus accounted for by these latter variables in the macro-scale equations, which say that when the size-, manufacturing- and income-related components of overall environmental pollution have been accounted for, there are no additional relationships between environmental pollution and property values that are discernible. The difference in conclusions is one arising from differences in the scale of analysis, and in no way implies that one set of conclusions contradicts the others.

VI. INTRA-METROPOLITAN ANALYSES

A variety of exploratory and experimental studies of land use-environmental pollution relationships also were undertaken within metropolitan regions after first providing a detailed review, for each pollutant, of patterns of pollutant sources within metropolitan regions, generation factors, diffusion, dispersion and transport mechanisms, etc., consistent with the flow of causation diagrammed in Figure 2. No attempt was made to achieve comprehensiveness or completeness, because of the limitations inherent in the data sources. Rather, the intent was to investigate potentially fruitful lines of inquiry. Two of these lines will be noted here, because of their different links to urban form: (a) relationships of air pollution to urban densities; and (b) patterns of water quality in a complex hydrologic situation.

A. Sample Density Relations

It is known that population densities within urban regions drop off with distance from the city center in a negative exponential manner ($d_x = D_c e^{-Bx}$) where d_x is population density at distance x from the city center, D_c is density at the city center, and B is the density gradient, the rate at which densities fall with increasing distance.

Such density gradients were fitted to data obtained for each of the 13 sample regions for the censuses of 1950, 1960, and 1970. It was found that in each census year, larger cities have higher central densities and flatter density gradients, whereas in all cities in the 20-year period, central densities have been declining in absolute terms and density gradients have been becoming flatter as urban dencentralization has progressed.

The question that then was posed was whether air pollution showed similar gradient patterns and changes. In several cases, it was found that a similar equation describes the spatial pattern of air pollution, but comparable data were unavailable to relate unfolding urban decentralization to changes in the pattern of air pollution.

Some experimentation also took place with both solid wastes and noise data, and it was found that these, too, were density-related, suggesting that they might be profitably subjected to density-gradient analysis as better data become available in the future.

VII. SUMMARY

To summarize, the following are some of the main principal conclusions of the statistical analyses presented in Land Use, Urban Form and Environmental Quality:

FINDINGS FROM MULTIPLE REGRESSION ANALYSIS
WITH PROPERTY VALUES AS
THE DEPENDENT VARIABLE

1. Property Values:

   a. Increase with metropolitan size
   b. Decrease with manufacturing concentration
   c. Increase with high-income population

2. Environmental quality is better in high-income cities than in low-income cities.

3. When population size, manufacturing concentration, and income level are taken into account, differential environmental pollution levels have no effect on property values.

4. When cities were grouped by population size, population size still affected property values in a positive fashion and manufacturing affected property values in a negative fashion for cities within a group.

5. The relationship between property values and city size follows an S-shaped curve, which means that for small and large city sizes, a change in city size produces a larger increase in property values than is true of medium city sizes.

6. Total property values are greater in low-density dispersed urban regions than in high-density concentrated regions, when population size, manufacturing concentrations and income levels are taken into account.

FINDINGS FROM MULTIPLE REGRESSION ANALYSES WITH LAND USE AS THE DEPENDENT VARIABLE

1. Urban form plays a significant role in translating city characteristics into land use.

2. Land use plays a significant role in expressing the effects of urban form on environmental pollution.

3. Residential land use:

    a. Increases with metropolitan size
    b. Decreases with income levels
    c. Increases with manufacturing employment
    d. Decreases in high-density core-oriented cities
    e. Increases as the city area increases and as the number of circumferential highways increases i.e. as urban sprawl increases in dispersed urban regions

4. Other land uses:

    a. Commercial and extractive land use
        - increases with city size
        - decreases when the density gradient is steeper
        - decreases with income levels
        - increases with manufacturing concentrations
    b. Open space
        - decreases with city size
        - decreases with manufacturing concentrations
        - increases with income levels
        - increases when the density gradient is steeper

SELECTED WATER RESOURCES ABSTRACTS

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Brian J. L. Berry

Department of Geography and Center for Urban Studies
University of Chicago
Chicago, Illinois

1HA098

801419

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16. Abstract

This executive summary contains highlights of the full study which focused on the relationship between land use forms and environmental quality. It investigated the influence of the spatial distribution of land rises on the pollutants generated and the resulting environmental quality. The investigation was assisted by the preparation of a "sorting table" in which the "rows" are the various urban forms and land use patterns and the "columns" are the several classes, types and elements of environmental pollution.

A comparative analysis of the materials assembled for the table determined trends across the urban forms and land use types, focusing particularly on the identification of those land use forms that naturally generate the least pollution. Also, parallel investigation of national trends in population distribution and land use was performed, so that some expectations could be developed as to the likely impacts on pollution of current patterns of regional growth and change.

17a. Descriptors

17b. Identifiers

17c. COWRR Field & Group

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